

Biospheric Sciences

Biospheric Sciences at Goddard Space Flight Center (GSFC) encompasses a broad range of basic and applied research to study terrestrial ecosystems and their interactions with the atmosphere using multi-scale remote sensing, modeling, and advanced analytical techniques. Experiments and investigations of a scientific nature utilizing Earth observations, new techniques and capabilities enhance our understanding of global processes for Earth System Science. Specifically, the Biospheric Sciences Branch:

- (1) Utilizes ground, aircraft, and satellite remote sensing instruments to measure variables that describe the temporal and spatial dynamics of natural ecosystems as well as human impacts on these systems, especially the vegetation condition (e.g., land cover, height, biomass, photosynthetic capacity), soils (e.g., soil condition and type), and links to atmospheric constituents (e.g., aerosols, CO₂);
- (2) Develops mathematical models which predict land surface conditions and processes related to rates of vegetation, soil, and atmosphere exchanges (e.g., radiation, heat, water, greenhouse gases, net primary productivity) as functions of remotely-sensed and ground-based observations;
- (3) Acquires, produces, and distributes comprehensive, integrated land data sets incorporating ground, airborne, and/or satellite observations to facilitate model development and validation;
- (4) Ensures the scientific integrity of new Earth remote sensing systems to improve space-based Earth observations by conducting calibration and validation studies and by serving as project managers and project and instrument scientists; and
- (5) Performs basic research, which leads to the definition and development of new technologies, sensors, and missions to advance state-of-the art capabilities for monitoring global changes.

Through the above activities the Branch assesses and predicts environmental changes due to natural and anthropogenic processes at local to global scales to improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere. Past studies include assessment of deforestation, desertification, land use, land cover, vegetation anomalies, primary productivity, famine early warning, biomass burning, ecologically-influenced pests and diseases, and the extent and impact of urbanization. Projects are organized under three sub-categories, Remote Sensing Research, Satellite Programs, and Field Campaigns.

Remote Sensing Research

The primary responsibility of the Branch is to facilitate the use of remote sensing to measure, monitor and understand the ecology of the Earth through research into remote sensing techniques, the development of new data processing techniques, and the development of new data sets. Following are descriptions of some activities in this area.

Aerosol RObotic NETwork (AERONET)

AERONET is a ground-based observational and research-enabling program designed to characterize the properties of aerosols in a vertically integrated column with sufficient accuracy to validate satellite-based aerosol retrievals from EOS satellite platforms. The Goddard-based program is designed to encourage domestic and international monitoring sites using standardized instrumentation (Figure 1). All instruments are calibrated to our NASA Goddard reference sun and sky-scanning radiometers. Because AERONET stations continuously transmit data to GSFC via

satellite links, the AERONET program provides processing in real time to the approximately 175 instruments in the AERONET federation.

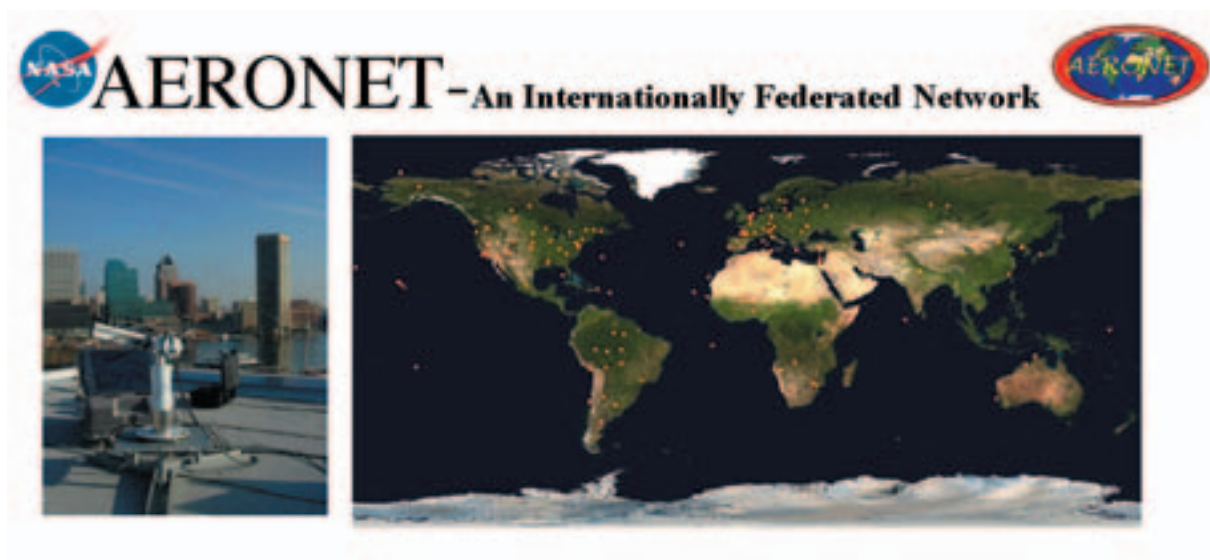


Figure 1. Baltimore-based Aeronet sun and sky scanning spectral radiometer (left) used at the 175 globally distributed sites (right) .

AERONET staff made considerable progress developing improved and new aerosol procedures and products that have furthered our goal of validation, to aerosol characterization and finally synergism with satellite observations. Holben et al., (1998) developed the concept of the program, Smirnov et al., (2000) developed and verified the cloud clearing algorithms, Eck et al., (2000) implemented world standard calibration procedures, Vermeulen et al. implemented polarization standards, and Dubovik et al., (2000 and 2001) have developed and implemented a revolutionary inversion code that is considered the world standard for allowing retrievals of microphysical, optical and radiative properties of aerosols not easily or accurately available from other observational platforms.

The AERONET, Branch, Laboratory and Directorate scientists and national and international agency scientists have made exceptional and increasing use of these data. The results for 2001 follow. Holben et al., (2001) provided a climatological monthly summary of the aerosol loading at a variety of globally-distributed sites. Continuously updated tables and graphs for all AERONET locations appear on the AERONET Web site (<http://aeronet.gsfc.nasa.gov>). AERONET has participated in a variety of field campaigns including SAFARI 2000 in the south African subcontinent, LBA in the Amazon basin, INDOEX in the northern Indian Ocean, PRIDE in the Caribbean, and Ace Asia in East Asia in the past three years. Eck et al., (2001, 2001) has characterized the optical properties from the SAFARI 2000 and INDOEX campaigns showing a dramatic increase in absorption of sun light by aerosols due to anthropogenic sources. Shafer et al., (2002) quantified the decrease in photosynthetically-active radiation at the surface in the Amazon basin attributed to extensive biomass burning aerosols. Smirnov et al., (2002) provided a definitive size distribution and aerosol-loading characterization of pure marine aerosols from a variety of mid-ocean sites. Dubovik et al., (2002) published a landmark paper on the optical, radiative and microphysical properties of aerosol types thus providing a clear road map for inclusion of aerosol properties in global climate models (Figure 2). Further efforts led by non-AERONET staff have provided published aerosol validation from AVHRR, TOMS, MODIS, MISR, and SeaWiFS in 2001 as well as validation of chemical transport models. Other areas contributed by AERONET research include anomalous absorption, background aerosol characterization and development of assimilation models and reference standard for hand-held sun photometer networks.

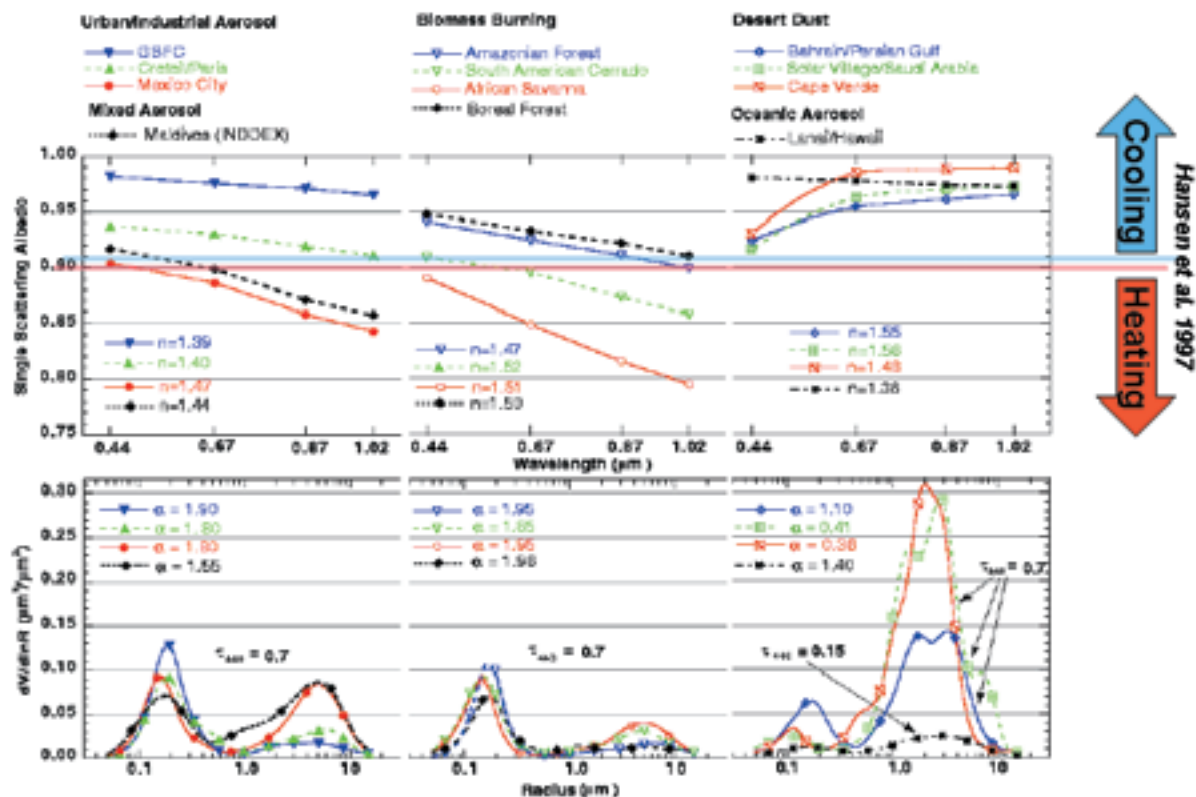


Figure 2. Aerosol optical, microphysical, and radiative properties, and their relationship to atmospheric heating/cooling, Dubovnik et al, 2002.

Web site: <http://aeronet.gsfc.nasa.gov>

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Interdisciplinary Study of Environmental Effects on Childhood Asthma

The Baltimore Children's Asthma project is a part of the new Environment and Health program at NASA/GSFC. Asthma ranks among the most common chronic conditions in the United States, affecting an estimated 17.3 million persons, including more than six million children. The number of children with asthma in the United States has more than doubled in the past 15 years. Asthma is the most common chronic illness of children in Baltimore City, accounting for approximately 20% of pediatric emergency room admissions, nearly four times the National rate.

In response to this common chronic illness, a multidisciplinary study has been undertaken, which incorporates the expertise and collaboration of NASA Earth scientists with mathematical modelers, medical doctors and researchers, health care officials, and representatives from Federal and local offices. The goal of the project is to predict pediatric asthma occurrence and to identify key environmental triggers of epidemics. The basic approach of the work includes the collection of clinical, climate, environmental, and remotely-sensed data into a comprehensive database and Geographic Information System (GIS). A data access and visualization tool utilizing a graphical user interface for formatting, obtaining, and graphing data is used with the integrated data from the GIS. Because of the number and diversity of data sets under investigation, both linear and complex non-linear modeling techniques are being used

to derive algorithms for predicting asthma and relating environmental triggers to asthma occurrence.

Results are expected to provide the first steps toward an early warning surveillance system for asthma which will identify epidemics, alert and educate the public and contribute to mitigating asthma events, as well as provide a prototype modeling technique that can be used for other regions, other diseases, or be applied to Homeland Security investigations involving human health.

Activities in 2001 included the development of a comprehensive database and GIS of clinical, remotely-sensed, and ground-based climate and environmental data, development of a Data Access and Visualization tool which will eventually be in a web-based format, and development of neural network models to predict pediatric asthma occurrence, and identify key environmental triggers. The project was awarded a grant from the Education Director's Discretionary Fund at GSFC for working with Baltimore City school children to monitor aerosols with hand-held sun photometers for supplementing data needs. One journal article was accepted for publication in the "Journal of Asthma" and two additional papers have been submitted to other journals. Numerous oral and poster presentations were given, and the project investigators participated in newspaper and television interviews about this project.

Preliminary results of the modeling research found that acute asthma appears to be influenced by variables beyond socioeconomic factors and adherence to medical regimens indicating a potential link to environmental triggers. A strong seasonal pattern of hospital and emergency room admissions with highs during spring and fall and lows during summer and winter has been observed. The number and timing of major epidemics is the same for all age and racial groups, and is similar across the State of Maryland. Children between the ages of 5-14 years old appear to be most susceptible to triggers while 15-18 years old are the least. The first fall epidemic is largest over the 16 year data record. Asthma pediatric hospitalizations can be predicted based on temporal data ($r^2=0.8$, rmse 5-7) using neural network models.

A web page describing basic information about the children's asthma project has been posted as part of GSFC's "Healthy Planet" site at <http://healthyplanet.gsfc.nasa.gov/project2.html>

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VHF Radar Mapping of Forest Biomass in Panama

Scientists and engineers at GSFC and Zimmerman Associates International-American Electronics developed a Very High Frequency (VHF) synthetic aperture radar system to measure vegetation biomass in heavy forests. In 1996 the Biological Synthetic Aperture Radar (BioSAR) sensor, operating at 80-116 MHz was approved by the National Telecommunications and Information Administration (NTIA) to operate on an experimental basis in the U.S. This is the first VHF radar granted such permission. In 1998, in a cooperative project with DoD, the BioSAR was mounted on NASA's C-130 aircraft and collected data over a series of Smithsonian Tropical Research Institute (STRI) test sites along the Panama Canal Zone in the Republic of Panama (Figures 3 & 4). The sites were flown for the purpose of testing the use of VHF sensors to map above ground biomass in moist tropical forests. Data from BioSAR were collected in a series of parallel flight lines approximately 20 km in length along the canal. At least one flight line of the BioSAR coincided with each of the STRI field sites. After data collection a terrain-correction algorithm using Level 1 Digital Terrain Elevation Data (91.5 meter resolution) supplied by the National Imagery and Mapping Agency was developed and used to normalize the BioSAR response with respect to terrain slope and aspect. After terrain normalization, both incidence angle and frequency averaged the backscatter data for each cell. This provided a single pan-angle pan-frequency response value for each ground cell. The nadir responses were not included in the averaging.

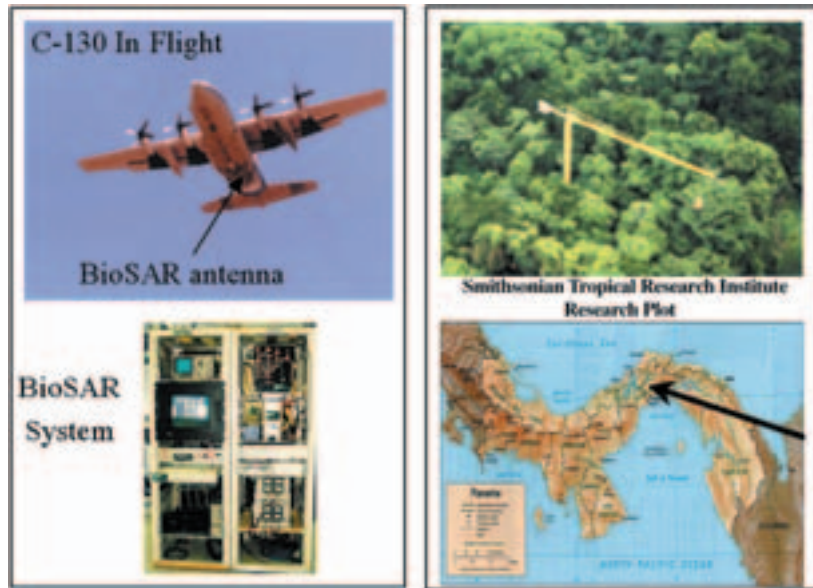


Figure 3. (left) The BioSAR system, the C-130 it is mounted on.
Figure 4. (right) The test site in Panama.

A physics-based semi-empirical model was used to relate biomass to normalized radar cross section. This approach was chosen because the scattering geometry is complicated enough that an analytical model of reasonable accuracy is not tractable, and there is insufficient data to construct an empirical model. As the BioSAR instrument matures, however, this situation will change, and empirical modeling based upon collected data and ground truth will be a more attractive option. The biomass model was applied to the BioSAR signal data and biomass estimates were made for each cell. An interpolation routine from ARC/INFO was applied to construct a biomass surface map for the largest segment of parallel flight lines (Figure 5).

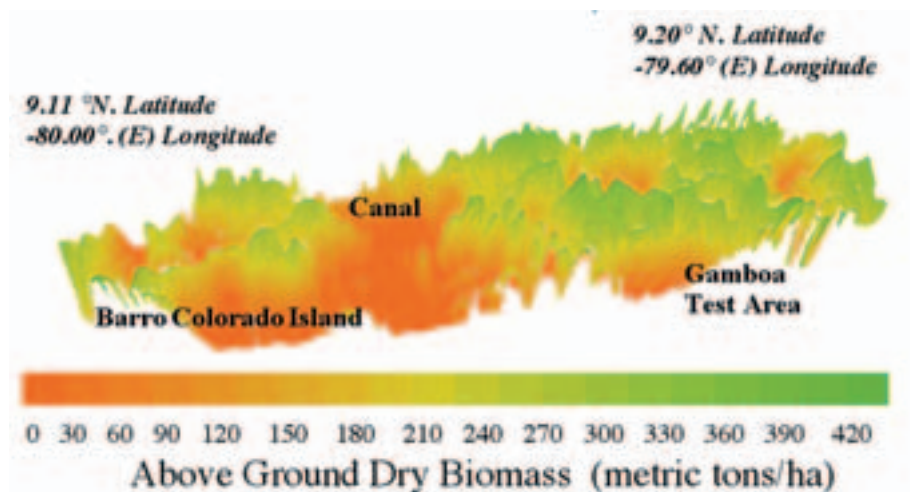


Figure 5. BioSAR generated Biomass Map, section of the Panama Canal Zone, Panama.

Accuracy testing was achieved by matching the sensor-derived biomass values for the 11 STRI research sites with the ground truth. Results show that there was good agreement ($\pm 10\%$) between the sensor-derived estimates of above ground biomass and the field data (Figure 6).

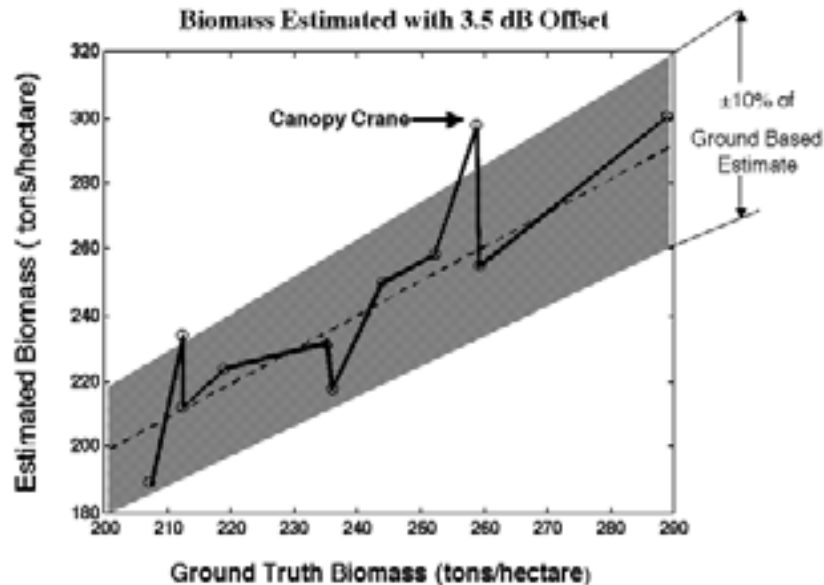


Figure 6. BioSar estimated biomass and field estimates for eleven tropical forest sites.

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A Forest Inventory of Delaware Using Airborne Laser Data

NASA, the Delaware Forest Service, and the Smithsonian Environmental Research Center are working on a project to measure Delaware's forests using an aircraft-mounted laser. The primary objective of this study is to test the laser, ground-sampling procedures, and computer programs used to inventory Delaware's forests. A helicopter carrying a small laser and video camera was flown 150 meters above terrain at 50m/s (180km/hour) over flightlines totaling over 5000 km in the summer of 2000 (Figure 7). The laser collected distance measurements from aircraft to ground 200 times per second as it flew north-south transects. The laser system is eye-safe; someone looking directly up at the laser as the helicopter passed overhead would see nothing but the helicopter and perhaps the laser/camera mounted on the underside. The laser emits near-infrared light ($0.905\ \mu\text{m}$) that is beyond the visual sensitivity of the human eye.

The laser traced the top of the forest canopy and these measurements are used to estimate the height and density of the trees. (Figure 8.) These and other laser measurements can be used to determine the amount of wood in the forest, specifically standing biomass - the weight of the wood, limbs, leaves, etc. - and the merchantable volume of the wood. Woody biomass is related to the amount of standing carbon in the forest. Carbon stores are of interest to researchers who deal with carbon cycles, carbon sources and sinks, and global warming. Merchantable woody volume is of interest to field and industrial foresters who are responsible for sawtimber and fiber production.

Ground measurements were collected over the summer and fall of 2000 to develop the mathematical equations needed to predict biomass or volume from the aerial laser measurements. Throughout the state there are 142 - 40m long ground transects, their locations stratified using a statewide digital map of land cover types developed and maintained by the University of Delaware (<http://bluehen.ag.s.udel.edu/spatlab/>). Eight land cover classes (i.e., strata) were considered: hardwood forest, mixedwood forest, conifer forest, wetlands, agricultural areas, residential areas, urban areas, and open water. Ground measurements were acquired in all but the open water class. In addition to estimating forest biomass and volume, the laser measurements are being used 1) to estimate the amount of impervious surface area, by stratum, statewide, and 2) to locate specific areas along

the flight transects which might provide suitable habitat for the Delmarva fox squirrel. Impervious surface area and changes to that area over time are of interest to environmental monitoring agencies, since impervious surfaces, especially roads and parking lots, are nonpoint pollution sources. In addition, impervious surfaces act as barriers to aquifer replenishment, and increases in impervious surface area indicate a loss of agricultural productivity. The U.S. Fish and Wildlife Service is interested in identifying potential sites for reintroduction of the fox squirrel, an endangered species endemic to the Eastern Shore. These animals frequent tall, dense, multistory forests, and the laser measurements are used to identify candidate areas for reestablishment.

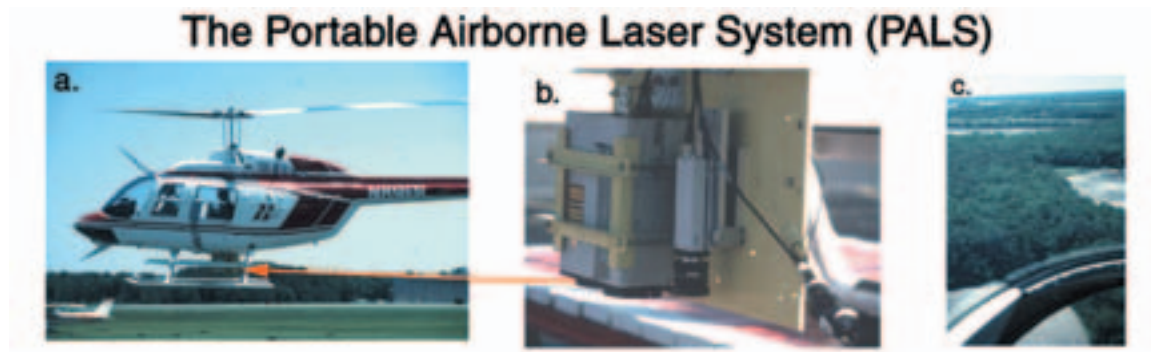


Figure 7. (a) Bell 206 JetRanger helicopter with PALS. (b) Laser Transmitter/Receiver and CCD video camera. (c) In flight over Delaware.

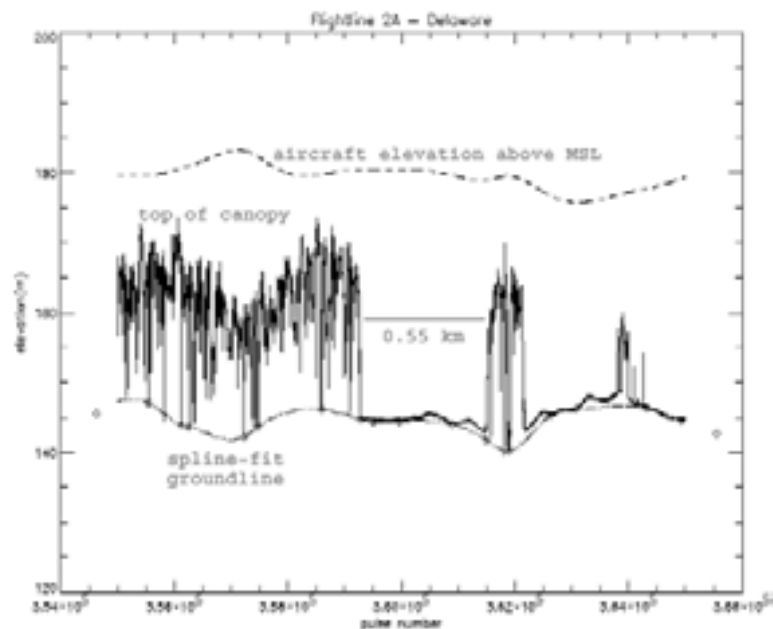


Figure 8. A 10,000 pulse, 2.5 km segment of laser flightline flown over Delaware during the summer of 2000. The sequential laser measurements made every 0.25m along-track progress from left to right as the laser traverses 20-25m tall forest canopy and agricultural fields. The diamonds represent local minima which define ground beneath the vegetated canopy. The topmost dashed line is the height of the aircraft above mean sea level.

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Global Inventory, Mapping and Monitoring Studies (GIMMS)

The Global Inventory Mapping and Monitoring Studies (GIMMS) is a group in the Biospheric Sciences Branch, which uses satellite data to study global vegetation phenomena, including global primary production, global extent and variations of deserts and semiarid areas, tropical deforestation and habitat fragmentation, and climatically-linked diseases. Three 2001 studies are described below.

Higher Northern Latitude 1982-1999 Photosynthetic Trends

Data were processed for the July 1981 to December 1999 daily global satellite record of 4-km data from the Advanced Very High Resolution Radiometer (AVHRR) instruments carried by the National Oceanic and Atmospheric Administration's (NOAA) polar-orbiting meteorological satellites. Data from channel 1 (0.55-0.68 μm) and channel 2 (0.73-1.1 μm) were used to calculate the Normalized Difference Vegetation Index (NDVI) as $(2-1)/(2+1)$. Data from NOAA-7 (1981-1985), NOAA-9 (1985-1988), NOAA-11 (1988-1994), NOAA-9 (1994-1995 from the descending node with ~ 0900 hours local solar overpass time), and NOAA-14 (1995-1999) were used.

The NDVI is used as a surrogate for photosynthetic capacity, as this spectral measure is highly correlated to the absorbed fraction of photosynthetically-active radiation and thus gross photosynthesis. A total of $\sim 40,000$ orbits of AVHRR daily data were used from 4 NOAA satellites. Calibration coefficients were applied after Los (1998). A time- and latitude-varying atmospheric correction was applied for the El Chichon (1982-1984) and Mt. Pinatubo (1991-1993) stratospheric aerosol periods. The resulting data were coherent and transitions between satellites were non-existent (Figure 9).

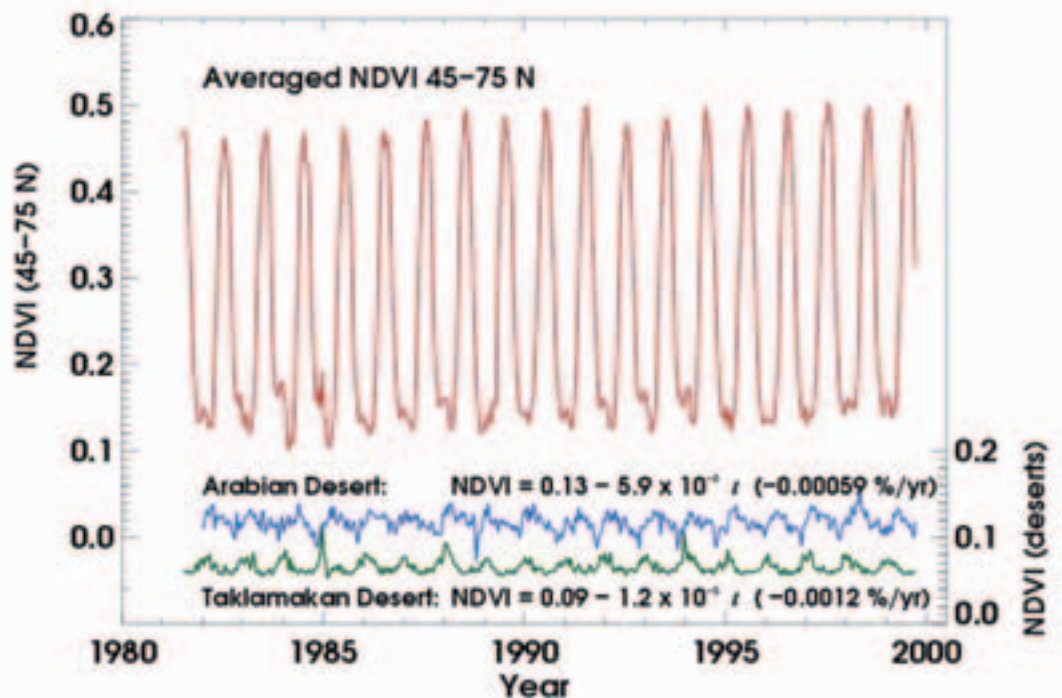


Figure 9. Time series normalized difference vegetation index data from 45° to 75° N, from the Taklamakan Desert (40° N & 85° E), and from the Arabian Desert (25° N & 40° E) are plotted from July 1981 through October 1999. The slope of the time plot for the Taklamakan Desert is 0.000001 NDVI units per year, while the slope for the Arabian Desert is 0.000006 NDVI units per year.

Very significant variations in 1982 to 1999 photosynthetic activity and growing season length at latitudes $> 35^{\circ}$ N were found. Two distinct periods of increasing plant growth were apparent: 1982 to 1991 and 1992 to 1999, separated by a reduction from 1991 to 1992 associated with global cooling resulting from the volcanic eruption of Mt. Pinatubo in June 1991 (Figure 10). Average May to September normalized difference vegetation index from 45° to 75° N increased +9% from 1982 to 1991, decreased -5% from 1991 to 1992, and increased +8% from 1992 to 1999. Variations in normalized difference vegetation index were associated with variations in the start of the growing season of -5.6, +3.9, and -1.7 days, respectively, for the three time periods.

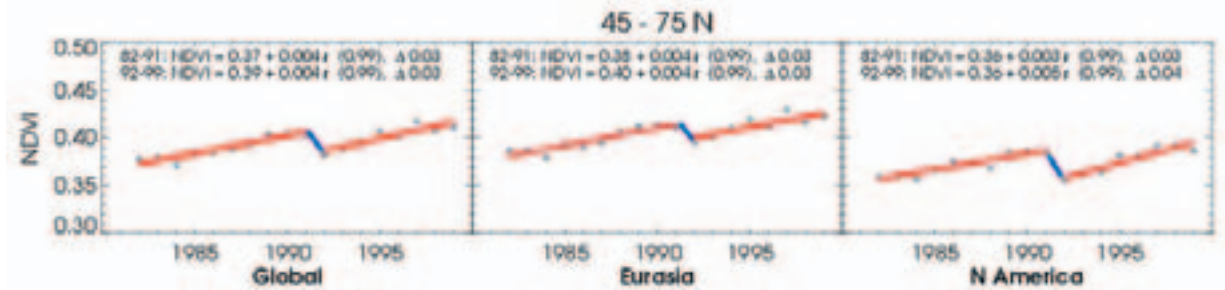


Figure 10. Plots of zonally-averaged $45^{\circ} - 75^{\circ}$ N NDVI data from 1982-1999 for Eurasia, North America, and the Northern Hemisphere for the May-September time period.

A statistically meaningful relationship between NDVI and land surface temperature for vegetated areas between 40° N- 70° N was found. That is, the temporal changes and continental differences in NDVI are consistent with ground-based measurements of temperature, an important determinant of biological activity. Together, these results suggest a photosynthetically vigorous Eurasia relative to North America during the past two decades, possibly driven by temperature and precipitation patterns (Figure 11).

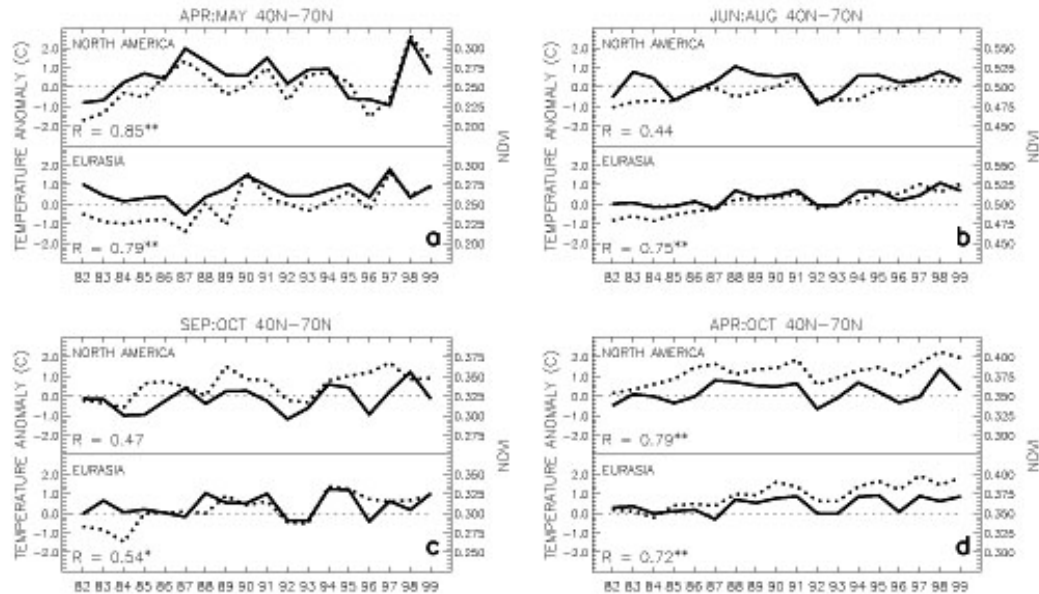


Figure 11. Spatially averaged NDVI (dashed line) and near-surface air temperature anomaly (solid line) between 40° N- 70° N: (a) April to May, (b) June to August, (c) September to October, and (d) April to October. “R” is the correlation coefficient. “**” (“*”) denotes the statistical significance at the 1% (5%) level.

Both 1982-1991 and 1992-1999 were two distinct periods of increasing satellite NDVI values, punctuated by a substantial decrease from 1991 to 1992. We conclude higher northern latitude vegetation is responding to warmer temperatures and starting the growing season earlier and continuing the growing season longer. This was interrupted by the eruption of Mt. Pinatubo in 1991, but had recovered by the late 1990's. Our analysis strongly supports a variety of different reports in the literature, ranging from animal migrations to arctic sea ice extent variations, of an earlier start and later end to the growing season at higher northern latitudes, directly linked to increasing surface temperatures (Figure 12).

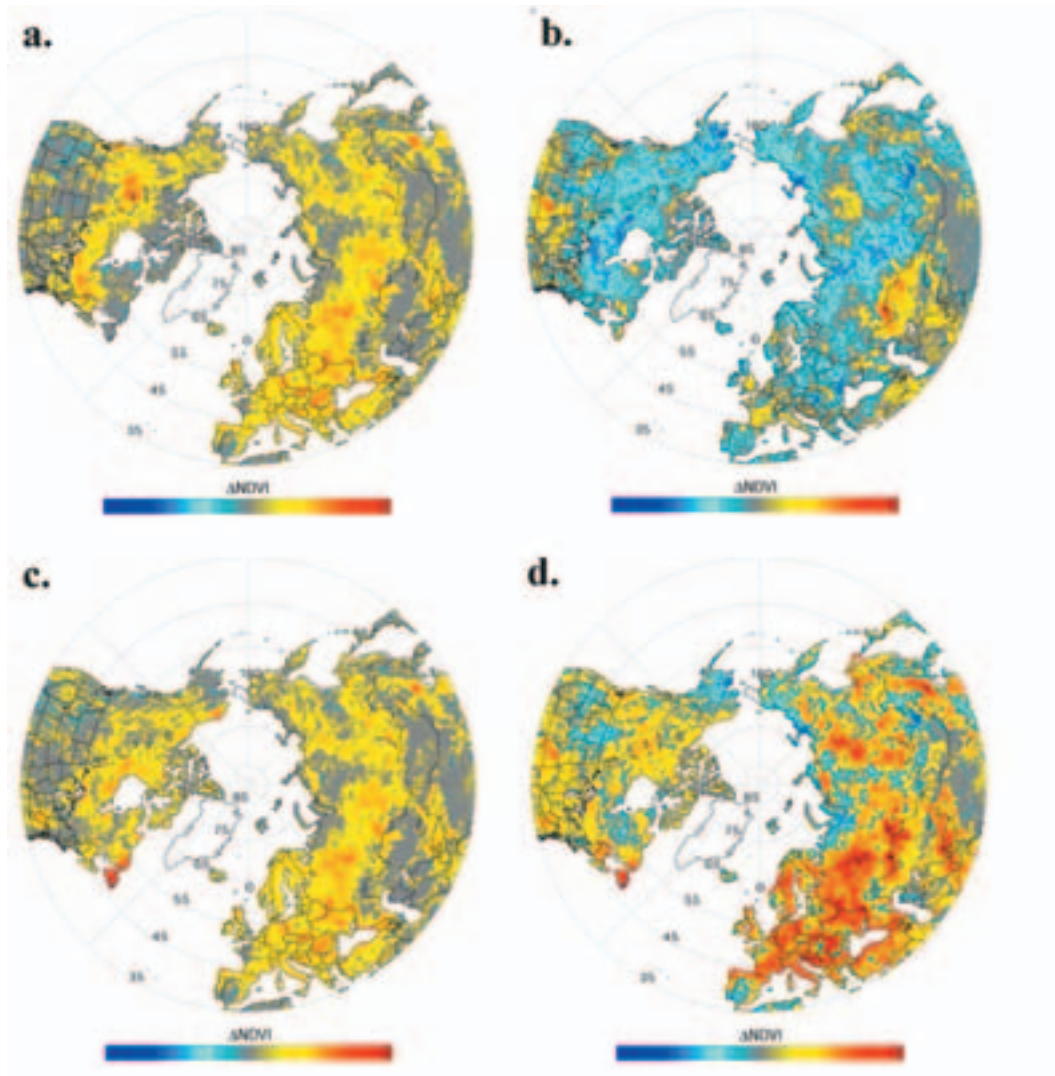


Figure 12. Northern Hemisphere plots of NDVI change 1982 to 1999 showing the areas of greatest NDVI increase. (a) 1982-1991; (b) the 1991-1992 cooling; (c) 1992-1999; and (d) the summation of figures 4a + 4b + 4c.

Satellite Hemorrhagic Fever Studies

The same NDVI intercalibrated time series data set illustrated in Figure 9 has been used to study ecologically and climatically-coupled hemorrhagic fevers in Africa. The satellite data is used as a surrogate for anomalous rainfall, which in turn is an “environmental” trigger for the emergence of Rift Valley Fever and Ebola hemorrhagic fevers from their reservoir(s) and/or the emergence of transmission vectors.

Rift Valley fever (RVF) outbreaks in East Africa are closely coupled with above normal rainfall that is associated with the occurrence of the warm phase of the El Niño / Southern Oscillation (ENSO) phenomenon. Outbreaks elsewhere in central and southern Africa are also linked to elevated rainfall patterns. Major RVF activity has been reported to occur throughout much of sub-Saharan Africa, except in areas with extensive tropical forest. In this study we used NDVI time-series data derived from the AVHRR instrument on polar-orbiting NOAA satellites to map areas with a potential for an RVF outbreak. A 19-year NDVI climatology was created and used to discriminate between areas with tropical forest, savanna, and desert.

Since most RVF outbreaks have occurred in regions dominated by savanna vegetation we created a mask to identify those areas where RVF would likely occur within the savanna ecosystems. NDVI anomalies were then calculated for the entire time series from July 1981 to the July 2000. Subsequently, we developed a methodology that detects areas with persistent positive NDVI anomalies ($> +0.1$ NDVI units) using a 3-month moving window to flag regions at greatest risk. Algorithms were designed to account for periods of extended above normal NDVI (by inference rainfall) and to consider the complex life cycle of mosquitoes that maintain and transmit RVF virus to domestic animals and people. The results indicate regions of potential outbreaks have occurred predominantly during warm ENSO events in East Africa and during cold ENSO events in Southern Africa. Results provide a likely historical reconstruction of areas where RVF may have occurred during the last 19 years. There is a close agreement between confirmed outbreaks between 1981 and 2000, particularly in East Africa, and the risk maps produced in this study (Figure 13). This technique is under testing with the U.S. Army's Walter Reed Medical Center for near real time monitoring of RVF disease surveillance in Africa and Arabia.

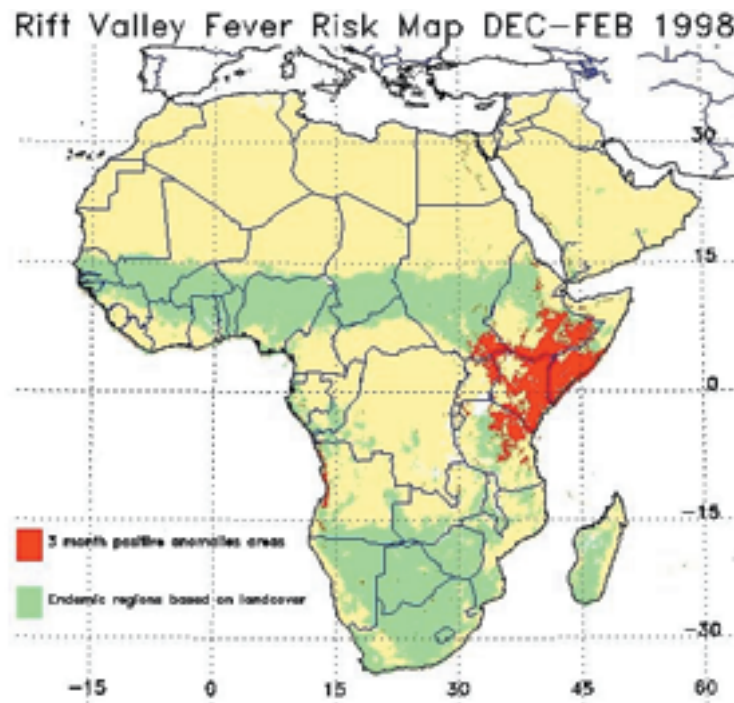


Figure 13. Based upon land cover and climate, the area within which Rift Valley Fever hemorrhagic fever outbreaks can occur naturally is determined. Our delineation corresponds to a very high degree with documented Rift Valley Fever outbreaks. Within the Rift Valley Fever stratum, we identify in red the areas where environmental conditions, using the NDVI as a surrogate for precipitation, are favorable for disease outbreaks. Our work has documented a high accuracy for identifying Rift Valley Fever outbreaks of natural origin.

Ebola hemorrhagic fever, named after the Ebola River in equatorial Africa, is caused by a virus in the filoviridae family. The Ebola virus first appeared in June, 1976, during an outbreak of 284 cases in Nzara and Maridi, Sudan with a case fatality rate (CFR) of 53%. In September 1976, a separate outbreak of 318 cases (CFR 88%) was recognized in Yambuku, Democratic Republic of the Congo. One fatal case was identified in Tandala, DRC, in June, 1977, followed by an outbreak involving 34 cases (CFR 64%), again in Nzara, Sudan, in July, 1979. The Tandala and subsequent Nzara outbreaks are thought to be directly related to the initial Nzara outbreak.

Ebola was not reported again until the end of 1994 when three outbreaks occurred within a relatively short time. In October 1994, an outbreak was identified in a chimpanzee study group in Tai, Cote d'Ivoire (12 chimpanzee cases, CFR 100%), with one non-lethal human infection. Forty-nine cases (CFR 59%) were reported the following month in northeast Gabon in the gold panning camps of Mekouka, Andock, and Minkebe. Later that same month, 315 cases (CFR 77%) were reported at Kikwit, DRC, from an unknown initial exposure thought to have occurred to men working in a charcoal pit. In Gabon, two subsequent outbreaks were reported in February and July 1996, respectively, in Mayibout II, a village 40 km south of the original outbreak in the gold panning camps (31 cases, CFR 68%), and a logging camp between Ovan and Koumameyong, near Booue (60 cases, CFR 75%); these are thought to be residuals from the initial Gabon November 1994 outbreaks. Table 1 lists the Ebola outbreak locations, times, and case fatality rates.

Table 1. Ebola Hemorrhagic Fever Outbreaks

date	location	case numbers	fatalities
June-November 1976	Nzara and Maridi, SUDAN	284	151
September 1976	Yambuku, CONGO	318	280
June 1977	Tandala, CONGO	1	1
July 1979	Nzara, SUDAN	34	22
October 1994	Tai, IVORY COAST	12/1	12/0
November 1994	Mekouka, Andock, Minkebe, GABON	49	29
November 1994	Kikwit, CONGO	315	242
February 1996	Mayibout II, GABON	31	21
July 1996	Booue, GABON	60	40

Table 1. Documented Ebola hemorrhagic fever outbreak locations, times, number of affected people, and fatalities. The October 1994 outbreak at Tai, Ivory Coast affected 12 chimpanzees and 1 human.

The occurrence of Ebola hemorrhagic fever in equatorial Africa is enigmatic. It is thought to result from, or to be facilitated by, human intrusion into previously uninhabited tropical areas, changes in the ecology of the Ebola virus or its natural reservoir(s), mutation of the Ebola virus, and even possible climate change. No reservoir or vector has yet been found from several thousand vertebrate and invertebrate species tested for Ebola antibodies.

Intensive surveillance for Ebola from 1981 to 1985 in the Congo identified 21 cases, suggesting the Ebola virus emerges from nature infrequently to infect humans, thus person-to-person transmission is limited and epidemics are rare. Tropical biodiversity is extremely high and it has been suggested tens of millions of tropical arthropod species alone exist. Thus it is not surprising that neither a natural reservoir nor vector for this rare and episodic viral disease has been identified; mutation from an arthropod or plant virus has even been suggested. Although little is known about the natural history of the Ebola virus, all known outbreaks of Ebola are associated with tropical forests.

The study of climatic and ecological conditions associated with Ebola hemorrhagic fever was to help determine the usefulness of satellite data for learning more about this unusual disease. The fact that simultaneous outbreaks occurred during two limited time periods in the 1970s and 1990s, suggested a possible environmental trigger for the Ebola outbreaks. Landsat was used data to investigate the ecological setting and degree of human intrusion at the various Ebola hemorrhagic fever outbreak locations. An AVHRR-based satellite-derived normalized difference vegetation index was used from 1981 to 1999 as a surrogate for precipitation, to investigate possible wet season/dry season transitions associated with Ebola virus emergence and to provide insights into potential vector(s). Because no time-series satellite data were available for the 1970s, the analysis was restricted to the 1990s outbreaks.

Landsat satellite data determined all outbreaks occurred in tropical forest, either continuous or gallery, with a range of human intrusions. Meteorological satellite data, spanning the 1981 to 2000 time period, showed that marked and sudden climate changes from drier to wetter conditions were associated with the Ebola outbreaks in the mid 1990s. Analysis of the NDVI anomalies at the three mid-1990 Ebola outbreak locations indicated unique conditions were apparent at this time within the tropical forest stratum of Africa (Figure 14) although only 2 of the 3 outbreak locations seemed sufficiently close to affected areas for there to be an associated “ecological trigger” event (Table 2). The work is continuing and data are being analyzed for the December 2001 and January 2002 Ebola outbreaks in Tropical Africa.

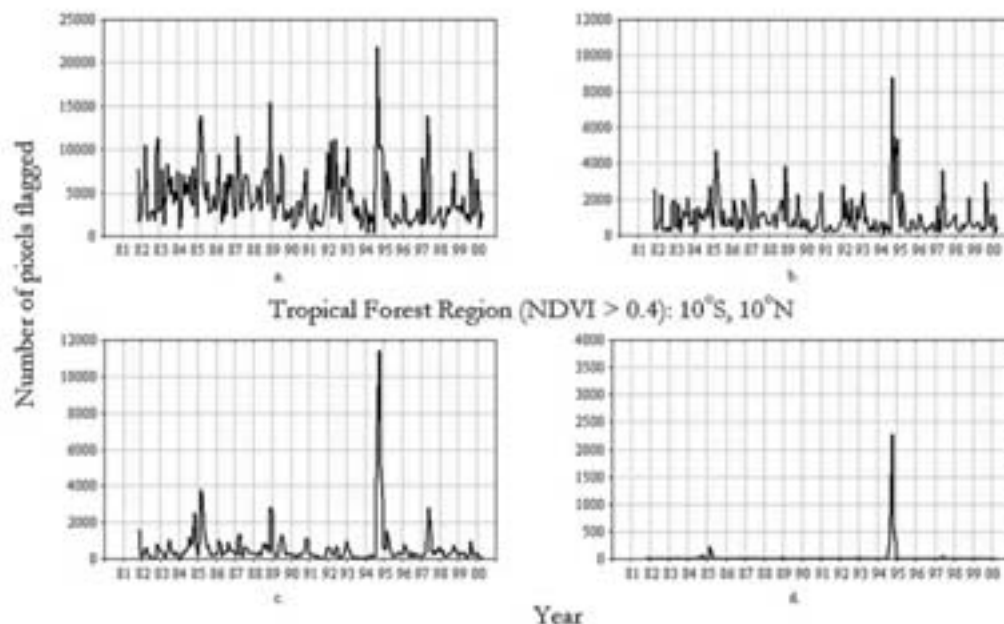


Figure 14. Using the NDVI profiles from the 3 Ebola outbreak locations in the mid-1990s, we computed the number of pixels in the tropical forest stratum of Africa where similar NDVI characteristics occurred. These were summed and plotted vs. time. (a) an NDVI of 0.025 with 2 months < 0.025 followed by 1 month > 0.025 ; (b) an NDVI of 0.025 with 3 months < 0.025 followed by 2 months > 0.025 ; (c) an NDVI of 0.05 with 3 months < 0.05 followed by 2 months > 0.05 without any pixels “filtered”; and (d) an NDVI of 0.05 with 3 months < 0.05 followed by 2 months > 0.05 where only those pixels surrounded by similar flagged pixels are included. Figure 14a pinpoints the 1994 Ebola outbreaks within our African NDVI data set. See also Table 2.

Table 2			distance from	distance from	distance from
			nearest to	nearest to	nearest to
year	date	number of flagged pixels	Tai (km)	Mekouka (km)	Kikwit (km)
			(Oct. 1994)	(Nov. 1994)	(Nov. 1994)
1994	July	53	701	297	576
1994	August	824	1,753	265	58
1994	September	2334	1,715	214	94
1994	October	729	215	58	504
1994	November	394	122	133	841
1994	December	9	511	1,225	754
1995	January	5	178	1,862	2,769
1995	February	30	1,570	202	715
1995	March	11	2,134	66	592
1995	April	2	2,230	403	783

Table 2. The distances from the nearest cluster of affected pixels to the three 1994-1995 Ebola outbreak sites. We used the criteria of a 0.05 Δ NDVI threshold with associated persistence of 3 months with <0.05 and 2 months >0.05 NDVI, which we treat as a surrogate for precipitation. An additional constraint required any affected pixel had to be surrounded by 8 other affected pixels. See also Figure 14. The dates of the first documented Ebola case(s) were October 1994 for Tai, Ivory Coast; November, 1994 for Mekouka, Gabon; and November 1994 for Kikwit, Congo.

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Global Carbon Cycle Science Planning

The global carbon cycle has recently become the focus of intense scientific, political and economic interest both nationally and internationally. This interest is motivated largely because of the potential for global warming and climate change caused by increasing atmospheric CO₂ concentrations as a result of human activities. The atmospheric concentrations of CO₂ are determined by the net exchanges of CO₂ (sources and sinks) between the atmosphere and the land and oceans. On an annual basis about half of the CO₂ produced by fossil fuel use and deforestation is absorbed by the land and ocean surfaces through mechanisms that are not well understood. Without better understanding it is impossible to predict with confidence how political, social and economic decisions may impact future climate. For this reason the U.S. Global Change Research Program (USGCRP) and the National Academy of Science along with various international organizations have identified global carbon cycle science as a top research priority. NASA by virtue of its global scale perspective and remote sensing capabilities has a central role to play in efforts to improve understanding, monitor change and forecast future behavior of the global carbon cycle. Recognizing this, NASA Headquarters asked GSFC to develop a plan for NASA's contributions to the national effort. A team was formed with staff from the Laboratories for Atmospheres, the Hydrosphere and Terrestrial Physics and STAC Directorate representing expertise in atmosphere, ocean and land carbon cycle science and technology development. Over the past year the team has held three workshops, supported NASA HQ in promoting a carbon cycle plan and is completing a comprehensive technical memorandum describing the results of the planning activity. Representatives from other NASA Centers, NASA HQ, other Federal Agencies and the carbon cycle science community contributed to all phases of the planning effort.

These workshops were convened to identify the measurement needs for addressing the relevant science questions, to identify what NASA supported activities would meet the measurement needs and finally to cost and prioritize these activities. The planning activity identified the following major topics where NASA must play a major role:

- Atmospheric composition (space and airborne CO₂ measurements, CH₄, CO)
- Land surface biomass
- Land cover change
- Ocean surface CO₂ exchanges and carbon stocks
- Coastal Ocean processes

Each topic includes technological, measurement and modeling elements.

This first phase of the planning effort is now completed and provides a road map for NASA's contributions to USGCRP carbon cycle science.

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Global Carbon Cycle Science and Biosphere – Atmosphere Interactions

1) Land cover change: Impacts on climate and primary productivity

Human activities, especially harvesting of forests and clearing land for agriculture, have significantly altered the land surface at global scales over the last two centuries (Figure 15). Rising population and increasing demand for resources in the future are expected to accelerate the conversion of land surfaces from their natural state. Land cover change can have a direct impact on primary productivity and indirect impacts on climate. For instance, the state of vegetation can influence surface albedo, roughness and the partitioning of absorbed net radiation into sensible and latent heat, all of which have the potential to feedback to the climate and primary productivity.

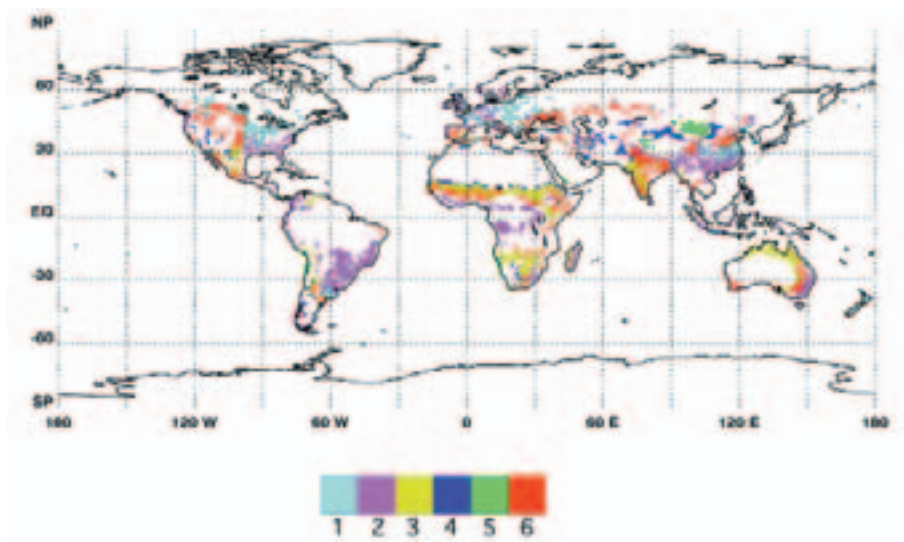


Figure 15. Regions where natural vegetation is predicted to have been substantially modified through conversion to agricultural use. The colors indicate different types of land cover change (e.g. 1 indicates forest to cropland conversion).

In collaboration with colleagues at the Departments of Meteorology and Geography at the University of Maryland, College Park, climate model simulations were run using current vegetation distributions derived from satellite measurements and compared to climate simulations in which vegetation distributions were specified for natural undisturbed conditions and for the year 2050. Results indicate that in the past most land cover change has occurred in temperate regions and has had the effect of increasing productivity and lowering temperatures slightly. Future land use change however, is likely to be centered in the tropics associated with warmer, drier conditions leading to lower productivity.

2) Impacts of fire on the global carbon cycle

The causes for interannual variability in the growth rate of atmospheric CO₂ are not well understood. Fossil fuel emissions are reasonably well known and do not vary year to year to the same degree as the atmospheric growth rate. Imbalances between photosynthesis and respiration must underlie this variability, but fires may also contribute through immediate emissions and secondarily by emissions from respiration of biomass killed by fire. Recovery after fire usually produces a sink for carbon as the carbon pools lost in fire accumulate. Fire suppression may lead to build up of organic matter that would otherwise be lost to fires producing a carbon sink.

Working with colleagues from Caltech, UC Berkeley and UMDCP we are working to estimate the contributions of fire emissions to the atmospheric CO₂ budget using the Carbon Cycle model, CASA, and observations of fires from the VIRS instrument on-board the TRMM satellite (Figure 16). The satellite observations start in 1998, at the end of a strong El Nino event extending to the present and indicate 20% year to year variability in number of fires observed. The number of fires is used to derive burned area. The CASA model predicts the amount of CO₂ emitted by fires based on burned area and carbon stocks. These predictions are compared to the atmospheric growth rate and to in situ observations reported by others. Our first results suggest that carbon emitted by fires can vary by 0.5Pg per year accounting for about 15% of the observed variability in atmospheric CO₂ concentrations.

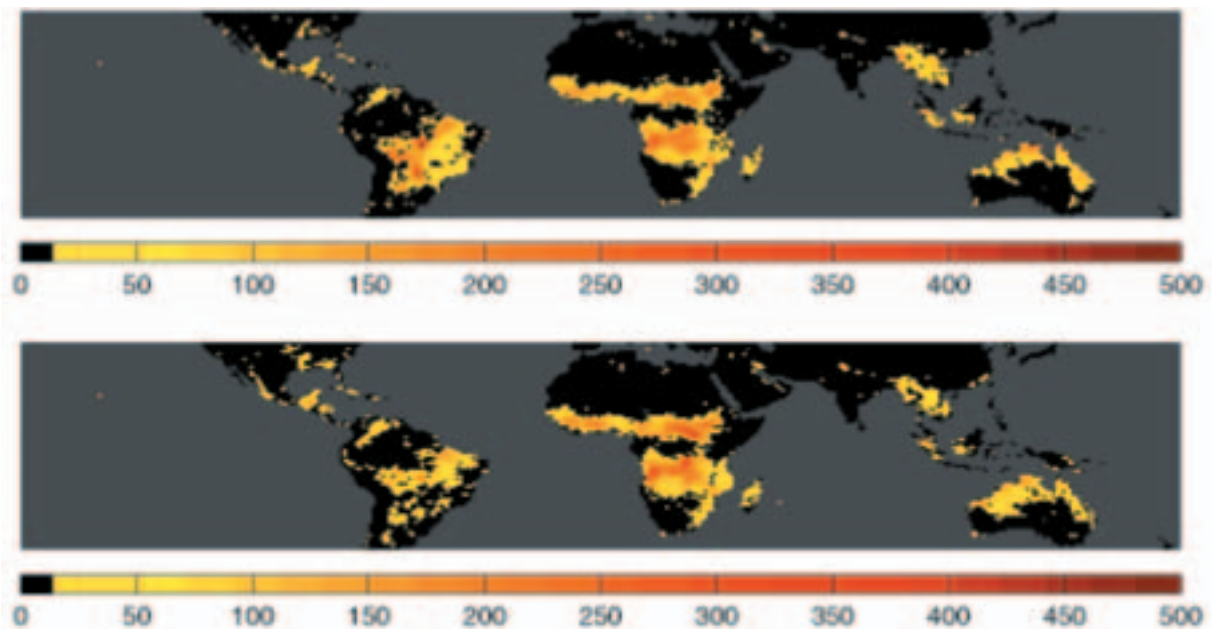


Figure 16. Maps of fire counts derived from TRMM satellite for 1998 (top) and 1999 (bottom)

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A Carbon Balance Approach to Measuring Human Impacts on the Biodiversity and Carrying Capacity of Ecosystems

Scientists at NASA's GSFC and Stanford University's Center for Conservation Biology, University of Maryland, Bowie State University, and the World Wildlife Fund have begun development of the first global integrated satellite and ground-based measurement system for using changes in carbon flux (net primary production) for assessing the impact of a broad suite of human activities on biodiversity and ecosystem carrying capacity. This research being carried out under both NASA's Land Cover Land Use Change (LCLU) Program and NASA's Carbon Cycle Science Research Program. The research focuses on the recovery of accurate broad-scale information on the location and extent of urban, suburban, industrial, and agricultural land cover types and describing their spatial relationship to conservation areas or ecoregions in the U.S. The Carbon Cycle Science component extends the study globally and begins to develop methods to quantify threats to biodiversity and ecosystem carrying capacity based on direct human action on the carbon cycle. Specifically, the carbon cycle science effort focuses on the direct human appropriation of Earth's net primary production (NPP), as a proxy for a broad spectrum of human activities, and quantifies the rate at which humans consume NPP vs the rate at which the Earth generates it.

For both projects satellite data from the Defense Meteorological Satellite Programs Operation Linescan System (DMSP/OLS) collected at night are used to provide a dramatic picture of urbanization on Earth through the detection of city lights (Figure 17).



Figure 17. DMSP/OLS Image showing Earth's city lights from space collected over a six month period in 1994-1995

Algorithms to generate accurate urban area estimates from these data were developed and tested for accuracy. The algorithms proved to be as good as census data in estimating urbanized area only with the distinct advantage of being able to describe the shape and location as well as area to create continental scale and global maps of urbanization. Good census data do not exist for many regions of the globe and even when available census data seldom provide shapes or precise locations for urban land cover.

The DMSP urban map data were combined with a Normalized Difference Vegetation Index analysis from AVHRR satellite data, and the world's largest biodiversity data base jointly devel-

oped by Stanford's CCB and the World Wildlife Fund to explore the spatial relationships between highly impacting forms of land use and species distributions in major ecoregions (Figure 18).



Figure 18. Merger of four data sets in a geographic information system (GIS) for model development and spatial analysis. Top to Bottom, DMSP “city light” data processed for accurate urban area mapping, Land cover map at 1km resolution, NPP calculations using the CASA model and 1 km resolution AVHRR data, and the Stanford/WWF ecoregions map for the United States.

For the LCLUC Program, three issues of critical importance to the science and policy of biodiversity conservation and sustainable development are being addressed: (i) identify areas of extreme threat to biodiversity due to anthropogenic habitat loss, (ii) analyze the fragmentation of ecosystems by urban and agricultural land conversion, and (iii) investigate human population and consumption patterns relative to the carrying capacity of the ecosystems that support them. This year, a suite of ecoregions in North America were identified that both contain high levels of biodiversity value and face extraordinary levels of habitat loss from anthropogenic land use change (Figures 19& 20).

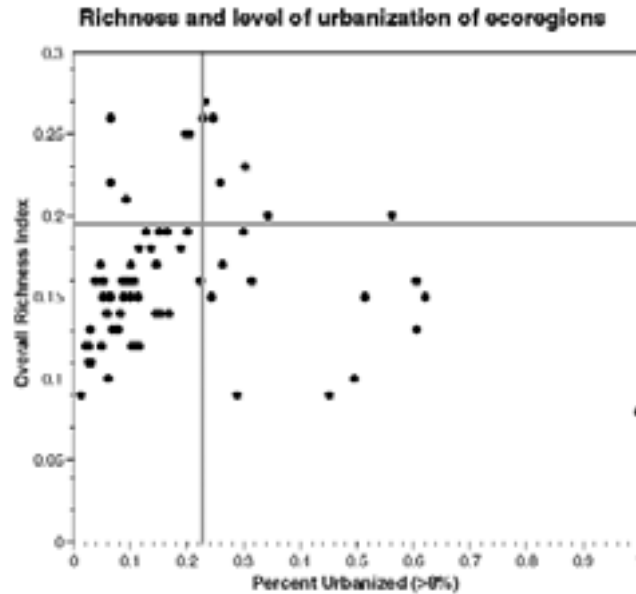


Figure 19. The horizontal axis is an index of habitat loss, in this case percent urban cover. On the vertical axis is an index of biodiversity value, for example species richness or endemism in a certain taxon, a composite index of diversity using all eight taxa, or the number of endangered species. Each point on the plot represents an ecoregion, and the heavy gray lines denote the upper quartile along each axis. The five ecoregions that lie in the upper quartile of both the biodiversity and habitat loss indices immediately emerge from such a plot as clear priorities for conservation attention, where levels of both biodiversity and human threats to it are extraordinarily high.

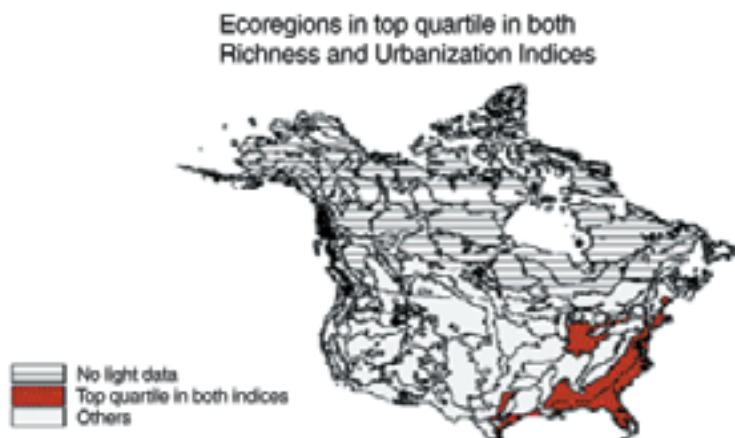


Figure 20. Map showing where high levels of species diversity or richness overlap with high levels of urbanization.

The Carbon Cycle Science work combines five global data sets and a NPP model to calculate the rate of NPP versus the rate of human consumption. The project will use the DMSP data combined with census data from the Center for International Earth Science and Information Network (CIESIN) and the United Nations Food and Agriculture Organization (UNFAO) to index the urban land use patterns to population density and create a global population density map. Human consumption of NPP will be quantified on a per capita basis using the UNFAO statistical data-

base on food and agriculture and equations from published sources that previously linked those data to NPP. The formulas for per capita consumption will be applied to the population density map to project human consumption of NPP in terms of mass carbon/area/time (e.g., kg C m⁻² yr⁻¹). AVHRR data of NDVI from the Global Inventory, Mapping and Monitoring System (GIMMS) will be used in conjunction with the Carnegie Stanford Ames Model (CASA) to simulate the total NPP of the land surface on a yearly basis from 1981 – 1998. These data will also be rendered in terms of mass carbon/area/ time. The carbon balance analysis will be merged with the USGS Global Land Cover Characteristics Data Base and a global ecoregion and species distribution data set recently created by the WWF containing 867 terrestrial ecosystems and allow the evaluation of anthropogenic threats to ecoregions and biodiversity at ecoregional, regional, and continental scales. Three issues of critical importance to carbon cycle science and the conservation of biodiversity: 1) Quantify, in a spatially explicit way, the appropriation of products of photosynthesis by human populations in terms of NPP relative to the ecosystems that support them. 2) Identify areas of extreme threat to biodiversity due to anthropogenic habitat loss and the stresses produced by high levels of NPP appropriation. 3) Analyze the fragmentation of ecosystems by urban and agricultural land conversion.

Early results for the U.S. show that urbanization has had a measurably negative impact on the total net primary productivity (NPP) of the land surface, carbon balance, and the food chain in the United States. At local and regional scales, urbanization increases NPP in resource-limited regions and through localized warming, “urban heat” contributes to the extension of the growing season in cold regions (Figure 21).

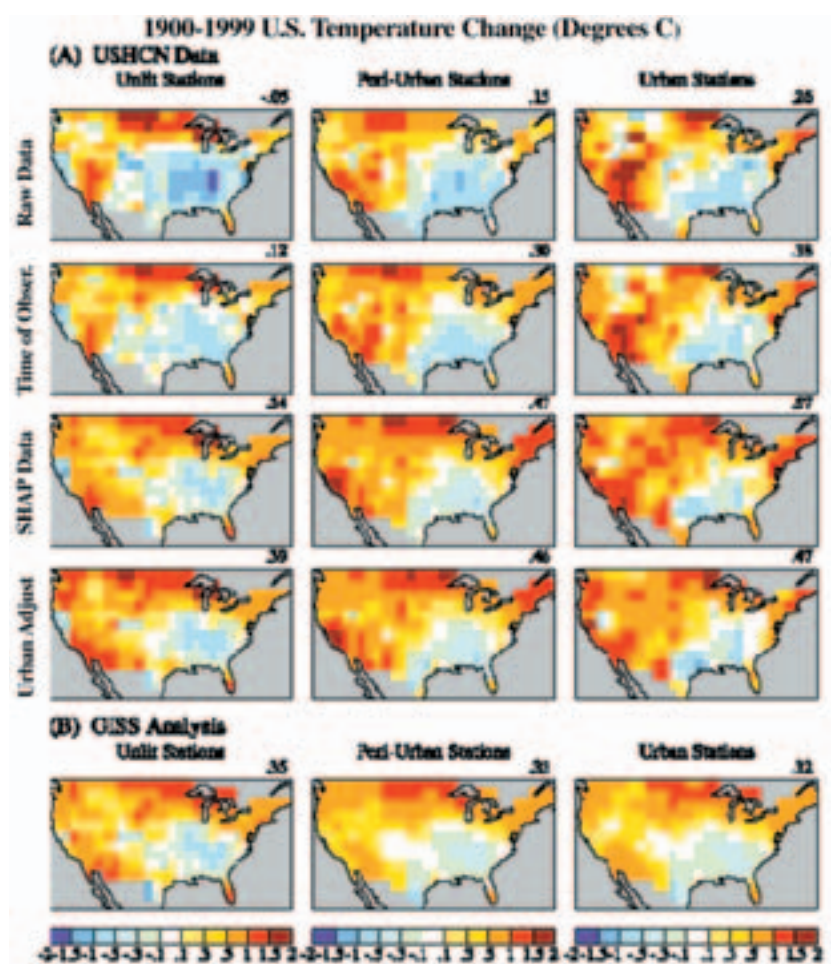


Figure 21. Goddard Institute for Space Studies results for reprocessing weather station data to remove effects from urban heating. Urban stations biased temperatures slightly obscuring the relative warming rate. After removal it was found that the rate of warming is actually greater than previously thought.

We found that urbanization is taking place on the most fertile lands and hence has a disproportionately large overall negative impact on NPP. Urban land transformation in the US has reduced the annual NPP by 0.04 Pg C or 1.6% of its pre-urban value (Figure 22).

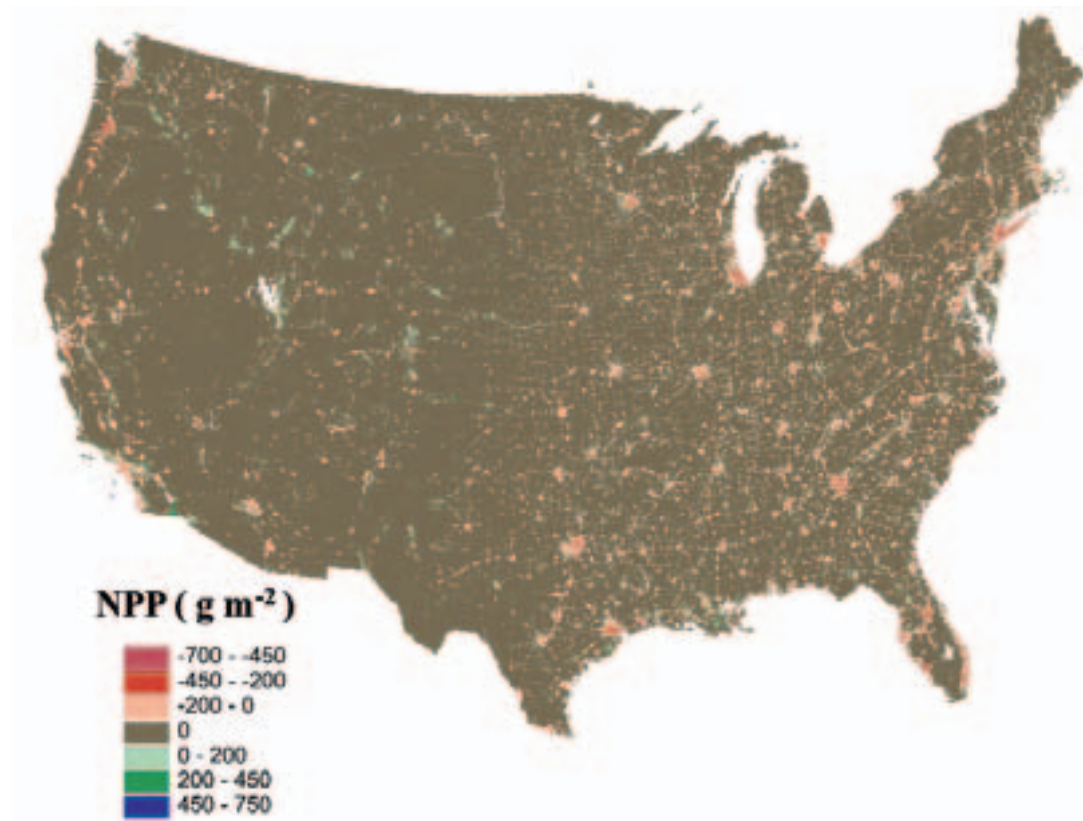


Figure 22. Results of pre-urban vs. post-urban simulation of NPP. Urbanization has resulted in the overall loss of 0.04 Pg C per year in the continental U.S.

The reduction is enough to offset the 1.8% gain made by the conversion of land to agricultural use, a striking fact given that urbanization covers an area less than 3% of the land surface in the US while agricultural lands approach 56% of the total land area. In terms of biologically available energy, the annual reduction in NPP is equivalent to $3.9\text{E}+14$ kilocalories – an annual loss to the total food chain roughly equal to the caloric needs of 448 million people. In terms of a direct correspondence to human food, the reduction of NPP due to urbanization of agricultural lands translates to the caloric requirements of 12 million US citizens per year – about 5 % of the total population.

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NASA/USDA Fluorescence Project

At the beginning of 2001, Dr. Elizabeth M. Middleton assumed the role of Project Manager for the collaborative NASA/USDA Fluorescence Project conducted at the Beltsville Agricultural Research Center (BARC). During 2001, existing MOUs were continued with two USDA/BARC research groups: the Hydrology and Remote Sensing Laboratory (formerly Remote Sensing Research Laboratory) and the Instrumentation and Sensing Laboratory. Instrumentation was upgraded, the fluorescence laboratory was moved to another facility at BARC, and our NASA field van with computer-operated boom was lost (replacement value ~\$250,000) in the 9/24/01 tornado.

Three years of funding (FY'02-'04) was successfully obtained in August 2001 under the NASA Terrestrial Ecology Program for a proposal reduced in scope from the original version submitted to the Carbon Cycle Science NRA in December 2000, entitled "Determining Photosynthetic Efficiency and Carbon/Nitrogen Cycling in Vegetation using Active and Passive Fluorescence Techniques" (PI, E.M. Middleton). This research will examine the role of nitrogen uptake on productivity in a variety of species. The use of spectral indices from fluorescence emissions and passive optical reflectance will be used to monitor vegetation status and estimate photosynthetic function of foliage. The relative merit of using optical vs. fluorescence spectral indices to assess vegetation vigor will also be examined, and the contribution of fluorescence to apparent "reflectance" will be quantified.

A second research program was developed in cooperation with the Army's Defense Threat Reduction Agency (DTRA), to examine the use of vegetation fluorescence in locating toxic waste sites. The NASA/USDA Fluorescence team gave two briefings to DTRA on fluorescence technologies in April 2001, and gave a formal presentation at a one day DTRA-sponsored workshop (Oct. 4) to address their proposed new program on Vegetative Effects Environmental Sensing (VEES). This proposal was accepted for a pilot study.

The 2001 research conducted at BARC by the Fluorescence Team included two week-long laboratory experiments to quantify the contribution of fluorescence to "reflectance", for healthy and stressed soybean grown in the greenhouse under different nitrogen regimes, in July and October. Three week-long experiments were conducted in August and September on field corn grown on plots provided different nitrogen fertilizer regimes. A variety of fluorescence technologies were used to acquire measurements on leaves, including images (~360 excitation) and line spectra (3 excitation wavelengths). In addition, spectral optical properties and physiological parameters were determined. The experimental protocol for determining the fluorescence/reflectance ratio in the Chlorophyll fluorescence peaks (685, 740 nm) were developed and implemented. We also examined emissions wavelengths produced in 5 nm bands surrounding the Fraunhofer lines at 677 and 745 nm.

A journal paper was published in Applied Optics (Jan. 2001, "Steady-state multispectral fluorescence imaging system for plant leaves" by M.K. Kim et al.) describing the fluorescence imaging system for foliage developed by the NASA/USDA Fluorescence team. Two papers were presented, and proceedings papers published, associated with ERIM's Third International Conference on "Geospatial Information in Agriculture and Forestry" held in Denver, CO in November 2001 (Campbell et al., Corp et al.). Posters were presented at the BARC Poster Day on April 25, 2001 and at the American Society of Agronomy Meetings held October 21-25, 2001 in Charlotte, NC on the theme "Sustaining Earth and its People— Translating Science into Practice". Collaborations were developed or maintained with several groups, including: NASA/Langley, on the development of a Fraunhofer line spectra instrument for Chlorophyll Fluorescence; and NASA/Stennis, to collaborate on the DTRA project; Dr. Joe Sullivan (U MD), to measure fluorescence of UV treated trees.

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Comprehensive Mapping of Northeast China Forests

Forests in Northeastern China have been changing dramatically due to both human and natural disturbances, including forest fire, insect infestation, logging, and agricultural conversion. At the same time, China has launched an aggressive reforestation campaign, with the area of planted forest in Northeastern China increasing by ~30% since the mid 1970's. The competition between forest loss through disturbance and logging, and forest gain through regrowth and planting will affect China's ecosystems, economy, and regional climate, and may also impact the global carbon cycle.

The study's aim is to create a forest-cover monitoring system for this region using multiple satellite data sources and GIS technology. The study is using MODIS, Landsat, and radar data to comprehensively map the extent and type of forests in Northeastern China, and assess how fast this cover is changing. Working in conjunction with researchers at Chinese Academy of Forestry in Beijing, the study is led by Drs. Guoqing Sun from UMD, Jeffrey Masek, Jon Ranson, and Darrel Williams all from Biospheric Sciences. The project is funded through the NASA Land-cover Land-use Change Program, and also acts as a pilot for the Global Observations of Forest Cover (GOFC) project, an international initiative to monitor forests around the globe.

Efforts during 2001 concentrated on two areas: (1) creation and intercomparison of initial forest-cover maps from MODIS and Landsat; and (2) assessing the carbon balance associated with a large forest fire in the region. Both of these efforts were supported by field work in China to measure biophysical properties of trees in the region.

The initial maps of forest cover were created through classification of multi-date MODIS images (500 meter resolution) using a decision tree classifier. By using multiple dates, both deciduous and evergreen canopy types could be distinguished. The majority of forests in the region are composed of mixed conifers and deciduous hardwoods. Some natural tracts of conifer exist in the Eastern highlands, near North Korea, while extensive larch forests occupy the northernmost regions. Planted forests include a variety of species, including larch and Korean pine. For individual provinces, forest cover ranges from 35% (Liaoning Province) to 43% (Jilin Province), in good agreement with published estimates from the Chinese Academy of Forestry. These results provide a baseline for monitoring future changes in the area and composition of China's forests. Efforts in the coming year will focus on determining areas and rates of forest cover change using over 100 Landsat TM and ETM+ scenes from the period 1990-2000.

The second thrust of the investigation centered on the 1987 fire in Daxinganling, which burned 1.14 million hectares of forest and nearly 25 million cubic meters of timber. Using Landsat and radar data in combination with field measurements, Dr. Sun mapped the burn intensity and determined the associated carbon release (18.9 million tons carbon) from one part of the burned area. This result demonstrates the possibility of converting mapped areas of disturbance to land-atmosphere carbon fluxes. The investigation also revealed differences between post-fire management practices in China and in nearby Russia. While moderately burned timber in China was harvested, it was left in the countryside, producing a distinctive signature in synthetic aperture radar (SAR) images.

Web site: <http://fir.gsfc.nasa.gov/cgi-bin/nasa/index.cgi>

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Siberian Disturbance Mapping Project

Siberia is a vast area encompassing over 50% of the world's coniferous forests. Land cover change in Siberia is driven by natural and anthropogenic factors, which may affect the carbon balance of the Boreal forest, which in turn may impact the global carbon cycle. A more thorough insight into the disturbance regimes of the northern coniferous forests is a crucial element in understanding the dynamics of global carbon cycling. Important factors affecting forest cover in this area are wild fire, insect outbreaks, logging, air pollution, gold mining and oil exploration.

The aim of this study is to produce land cover and land cover change maps that can be used to determine the extent and rate of natural and anthropogenic impacts on the Siberian boreal forest. Moderate resolution sensors, such as MODIS (Moderate Resolution Imaging Spectroradiometer) have a potential to map land cover change regionally provided the scale of the land cover change

and disturbance can be resolved at 250 m to 1 km. Higher resolution satellite data were used to detect various disturbance types in a central Siberian study, centered at 94° East and 58° North (Figure 23). This area is within the International Geosphere-Biosphere Program Western Siberian Transect. These higher resolution data were used to develop classification procedures for MODIS data combined with Radarsat data. The radar data was expected to provide a unique perspective to complement MODIS analysis and enables more detailed and accurate mapping of the disturbances that are under study. Areas of known change were examined using higher resolution (~30 m) satellite sensors (such as Landsat 7, Radarsat, ERS (European Remote Sensing Satellite) and JERS (Japanese Remote Sensing Satellite). Characteristic features related to forest disturbances were determined using image analysis techniques including decision tree classification and spatial texture analysis.

The accuracy of the results was determined by comparing map results with areas of known forest types. Ground studies, forestry maps and high resolution IKONOS data were used to identify and classify various land cover and disturbance classes. Results indicate that when available, high-resolution radar data improved classification of disturbance sites over Landsat 7 data alone. SAR (Synthetic Aperture Radar) data was especially suitable for detailed mapping of the complex landscape created by the juxtaposition of logged areas in different stages of regeneration and fire scars. The unique spatial and spectral patterns of the various disturbance types were noted. This information was used to classify land cover and disturbance on moderate resolution MODIS and Radarsat images. Forty per cent of the training areas were set aside for testing the classification. Texture measures of the Radarsat data (such as homogeneity, contrast, dissimilarity, mean, variance, and entropy) increased the information content of the Radarsat ScanSAR data. The combination of the radar and optical data provided better classification results of the central area than either data type alone. Merged data sets can provide a powerful tool for monitoring disturbance in the Siberian boreal forest (Figure 24).



Figure 23. Study area in central Siberia. Red lines and squares shows moderate and higher resolution intensive sites, green shows IGBP Western Siberian transect study area.

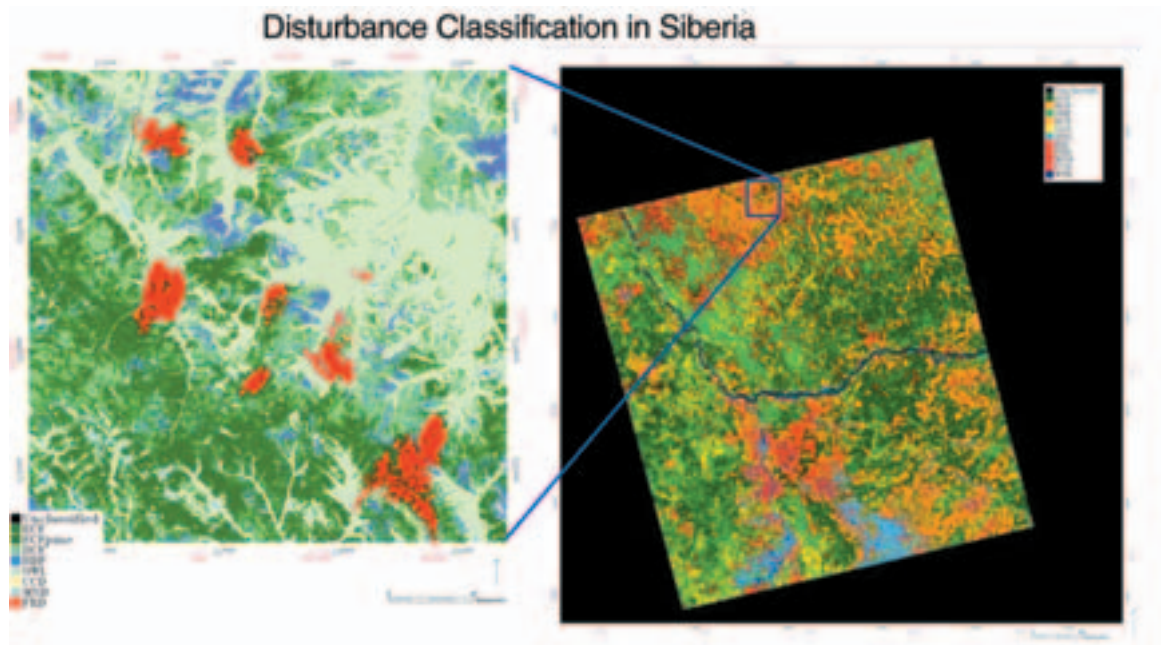


Figure 24. Hi-resolution classifications of forest disturbance from Landsat 7 and radars (Left) were used to develop regional classifications using MODIS and Radarsat data (Right).

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Siberian Leaf Area Index Study (SibLAI)

Collaborating with the Sukachev Institute of Forest Research of the Siberian Branch of the Russian Academy of Sciences, this year we completed the third in a series of summer field campaigns for a study that seeks to link surface measurements of leaf area index (LAI) with satellite data. The ultimate goal is to enable the creation of accurate LAI maps of the central Siberian region. LAI, which is the leaf area per unit area of soil surface, is a fundamental biophysical parameter through which surface vegetation can be related to remotely sensed observations. Our study focuses on the influence of fires on the boreal forest, and we have selected and sampled a chronosequence of post-fire stand ages to represent the changes that occur after a fire. Fire is of particular importance to this area of the world as boreal forests have been and continue to be shaped by the complex interactions of climate, fires, insects, and humans. With global climate change, shifts in disturbance regimes may occur, creating a need for better detection and understanding of the role of disturbances on these systems.

Our field campaigns thus far have been conducted in mixed dark coniferous forest northwest of the central Siberian city of Krasnoyarsk (approximately 57.3° N, 91.6° E). Our third campaign took place in July 2001 and consisted of a multinational team with participants from the U.S., Canada, and Russia, and included a new collaborator from the South Dakota School of Mines and Technology through the NASA Experimental Program to Stimulate Competitive Research (EPSCoR). The summer of 2001 saw the establishment of a new site of intermediate post-fire age and collection of surface measurements of LAI and a number of general forest characteristics necessary for satellite data interpretation on the new site and from the most recently burned site.



Preliminary data analysis shows that the relationship between plant area index (PAI), which is the total plant cover including both woody and leaf portions of the trees, and an index derived from satellite data, the normalized difference vegetation index (NDVI), is sensitive to age of the forest after burning. Recent field data are still being analyzed to obtain values necessary for the proper derivation of LAI, and we expect that our current statistical relationships improve after we have developed the more complete data sets; but it is clear that further work is required in order to develop the techniques for applying any relationships across the mixed boreal forest landscape. At a minimum, the effort will require classification of land surface types as well as the exploration of different vegetation indices. Siberian forest landscapes, like the one shown at left, are extremely complex owing to fire occurrence and variations in their intensity.

Additionally, our collaborative project has established the first Earth Observing System (EOS) core site in central Asia and is a node in NASA's AERONET program. The LAI estimates will provide ground data for land validation LAI products from the MODIS flying aboard NASA's Terra spacecraft. It will also provide information that will be beneficial for global-scale modeling efforts.

Web site: <http://ltpwww.gsfc.nasa.gov/bsb/lai/SibLAI.html>

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EO-1 Science Validation Effort and Hyperspectral Canopy Reflectance Modeling

The Earth Observing One (EO-1) satellite was launched from Vandenberg Air Force Base on November 21, 2000 as the first Earth observing platform of NASA's New Millennium Program. As part of this effort, NASA formed a Science Validation Team to contrast and compare the new sensor technologies with existing sensors such as the Landsat-7 ETM+. Theoretical canopy modeling and field experimentation were used to compare the EO-1 Advanced Land Imager (ALI) and hyperspectral Hyperion sensors with the ETM+ as part of this science validation effort.

The forest study site is in Durand-Eastman Park in Rochester, New York. The site consists of a

dense mature stand of maple, cottonwood, oak, and elm trees with an average height of 30 meters. During August and September of 2001, a detailed survey was conducted of the trunk locations, trunk diameter at 1.5 m, crown diameter, canopy dominance (lower, middle, and upper), and species of approximately 100 trees in a 30-meter radius. During the same period, meteorological, solar, and atmospheric measurements were collected by the Aerosol Robotic Network (AERONET) for use in atmospheric correction of EO-1 and Landsat-7 imagery.

Using the site characterization data, a synthetic scene was constructed (Figure 25) that approximated the same physical properties of the measured canopy. Employed were 3D ray tracing to compute canopy reflectance factors in the Hyperion wavelength channels, properly treating the multiple scattering between the leaves, leaves and soil, leaves and trunks, trunks and soil, and all scene elements in the synthetic scene to the sensor.

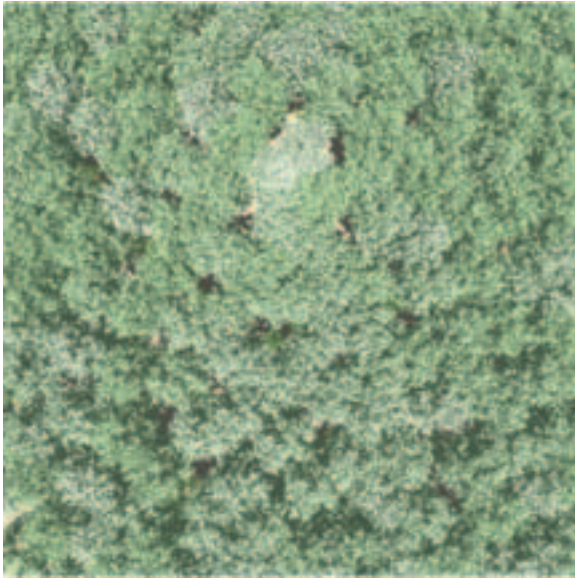


Figure 25.

Hyperion is an imaging spectrometer having a 30 m ground sample distance over a 7.5-kilometer swath and providing a 10nm-sampling interval of the solar reflected spectrum from 400 to 2500 nm. The instrument has a single telescope and two spectrometers, one visible to near infrared (VNIR) spectrometer and one short-wave infrared (SWIR) spectrometer. The VNIR spectrometer measures the spectrum from 400 to 1000 nm, and the SWIR spectrometer measures the spectrum from 900 to 2500 nm.



Figure 26.

The image at right (Figure 26) is an atmospherically corrected false color composite of data from Hyperion on August 25, 2001 (Red = Band 42 (773.31 nm), Green = Band 30 (651.28 nm), Blue = Band 16 (508.91 nm) over our test site. The bright red regions are forested areas, the gray and bluish regions are urbanized, and the dark blue region to the north is Lake Ontario.

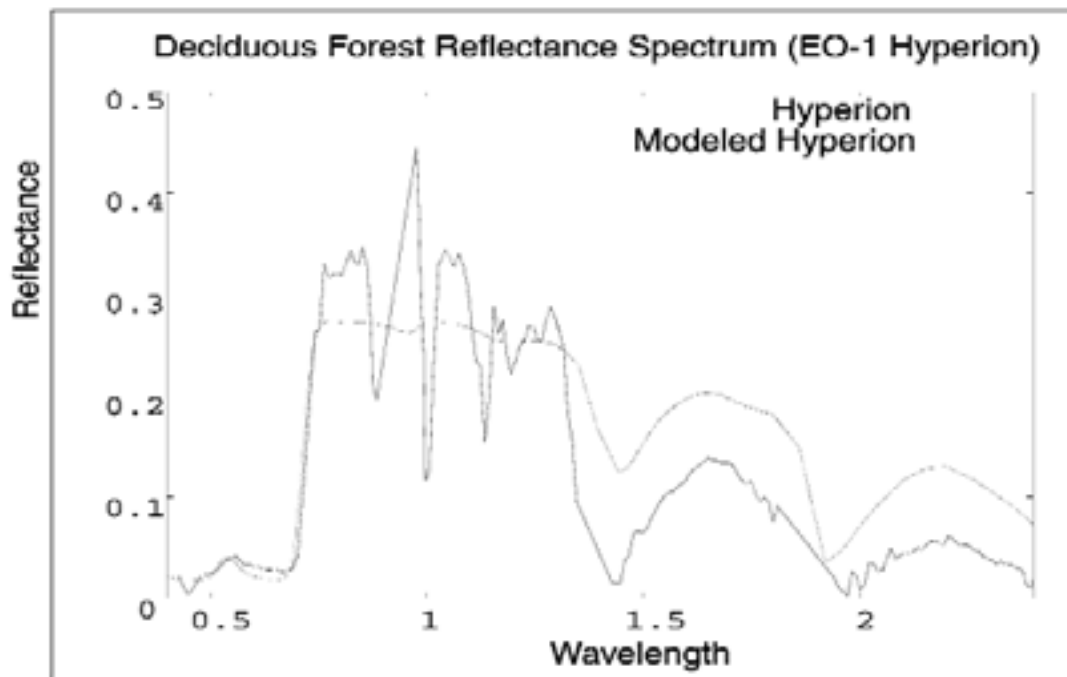


Figure 27. Plot of the average canopy reflectance extracted from the atmospherically corrected EO-1 Hyperion image and compared to the canopy reflectance model for the same Hyperion wavelengths. Overall, there was an agreement in the VNIR area but are typically showing higher reflectances in the SWIR area.

The work shows that the EO-1 sensors potentially can serve as spectrometers to compare model predictions over a variety of site conditions and types, if atmospheric corrections can be performed. AERONET derived parameters were used to perform the atmospheric corrections. Future investigations include the utility of atmospheric corrections derived from the high spectral resolution of the satellite data itself at appropriate wavelengths. The study will also use of such surface-derived spectra to constrain canopy reflectance model inversions in order to derive surface biogeophysical parameters.

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Satellite Programs

A major activity of the Branch concerns management of present and future satellite missions, either as Project Manager, Project Scientist, and Instrument Scientist or in the calibration and validation of the data. Following are descriptions of such activities, ranging from currently orbiting satellites to planned missions.

Earth Observing-1 (EO-1)

The Earth Observing One (EO-1) mission, launched in November of 2000, has proven to be a highly successful examination of technologies and techniques designed to effectively meet

NASA's Earth Science Enterprise (ESE) future space observation needs. Dr. Steve Ungar of the Biospheric Sciences Branch is the EO-1 Mission Scientist. The Advanced Land Imager (ALI) has paved the way for the next generation Landsat replacement instrument. The Hyperion Spectral Imager has demonstrated the efficacy of space borne hyperspectral imaging for addressing a variety of environmental observational needs.

The ALI has proven to be a cost-effective replacement for the ETM + instrument on Landsat 7 (Figure 28).

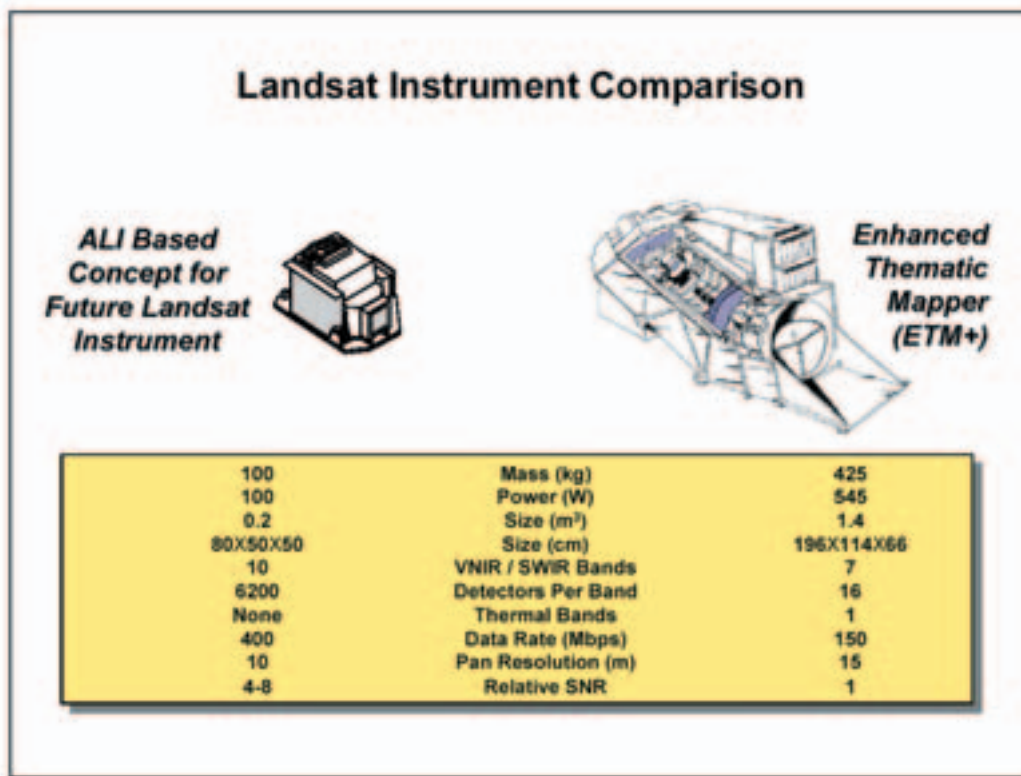


Figure 28. Landsat Instrument Comparison

ALI has proven to be superior to the Landsat 7 ETM + in the following areas:

- 1) higher signal-to-noise performance in all bands allows for more reliable detection of small variations in surface characteristics (e.g. algal blooms);
- 2) the pan band has proven more useful because of higher spatial resolution (10M), improved signal-to-noise, and more rational spectral coverage;
- 3) the addition of a short-wave blue band has improved the ability to estimate aerosol content and track coastal zone changes;
- 4) changing the band-4 spectral limits has made this important near infrared band insensitive to fluctuations in atmospheric water vapor content; and
- 5) the inclusion of a third band in the SWIR has positive ramifications for extracting information relating to geological features and vegetation canopy as well as fire and lava flow temperature estimates (Figure 29a).

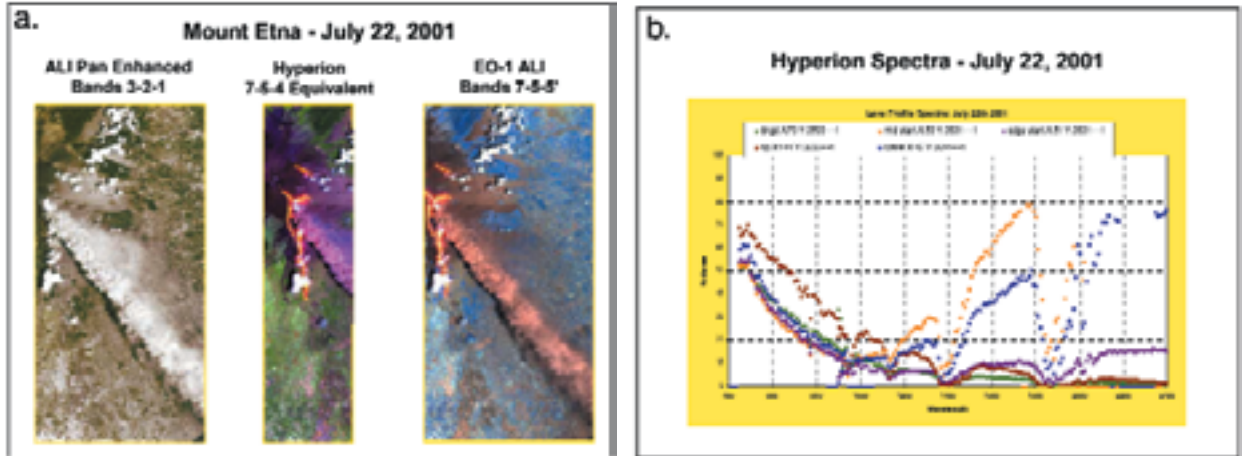


Figure 29a and 29b.

The Hyperion imaging spectrometer, a close derivative of the HyperSpectral Imager (HSI) instrument on-board the ill-fated Lewis Spacecraft, was constructed and installed on EO-1 in just under one year. It's performance has exceeded all expectations and it continues to provide detailed (10 nm) spectral measurements from 0.4 nm to 2.4 nm at a spatial resolution of 30m. Surface target information, not realizable with multispectral imaging systems, has been successfully extracted from Hyperion observations for a number of scenarios. The composition of volcanic plumes and the temperatures of associated lava flows have been successfully estimated (Figure 29). Exposed geological features have been successfully mapped (Figure 30). A number of studies tracking changes in natural vegetation and agricultural areas (Figure 31) are underway to assess the improved capability offered by spectral observations of landscape components.

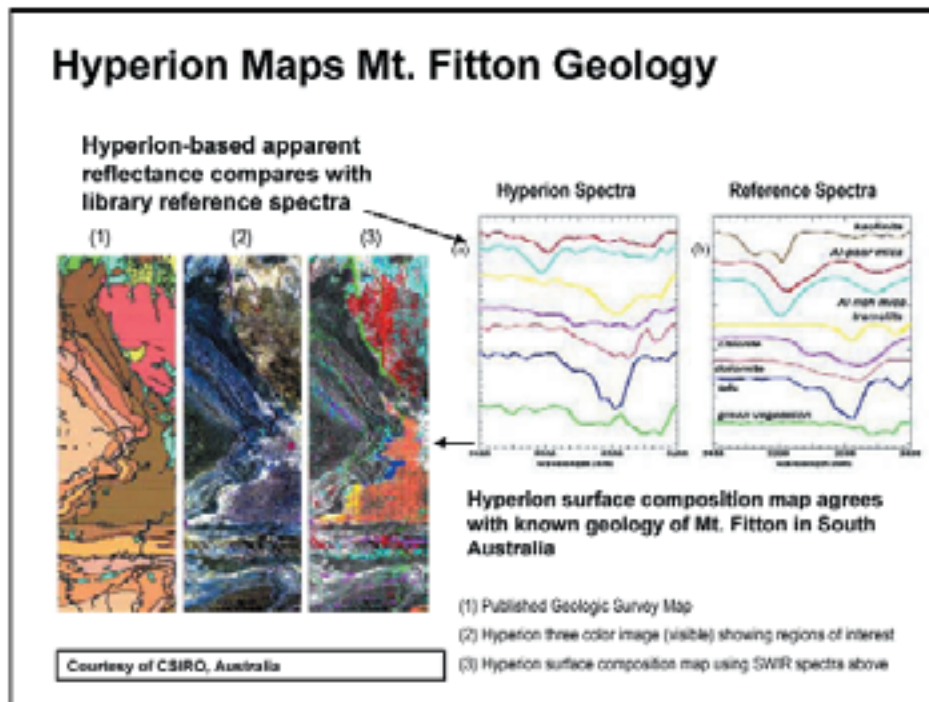


Figure 30. Hyperion Data for Mt. Fitton, South Australia.

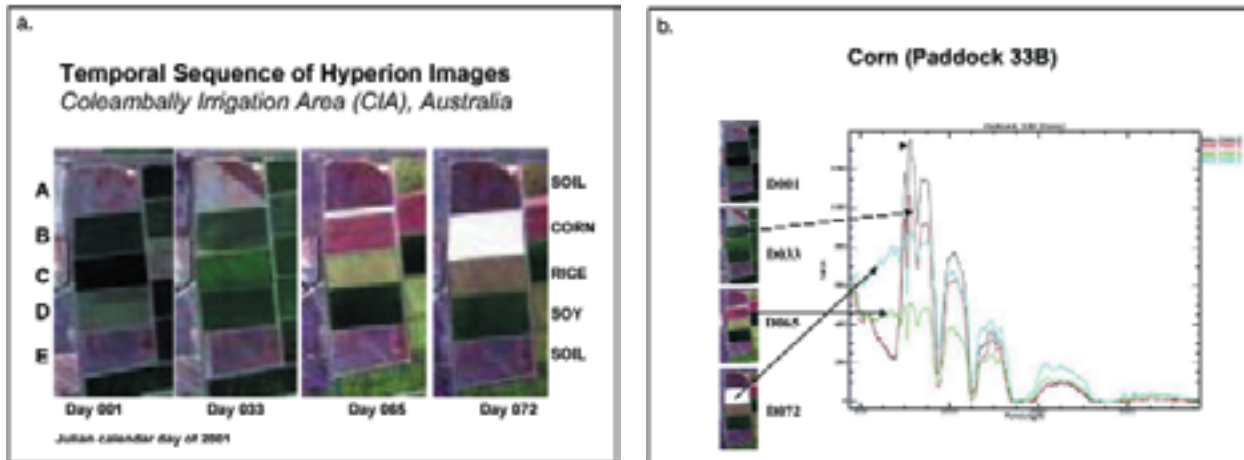


Figure 31. Hyperion data of agricultural sites in Australia.

Web site: <http://eo1.gsfc.nasa.gov/>

Contact: Stephen Ungar, Stephen.G.Ungar.1@gsfc.nasa.gov

Earth Observing System (EOS) Terra

Terra is the flagship platform for NASA's Earth Observing System Program. Dr. Jon Ranson of the Biospheric Sciences Branch serves as the Terra Project Scientist. The five Terra Spacecraft instruments have been providing scientific data since the instrument doors were opened on February 24, 2000. As of January 2002 all Terra instruments were collecting science data; however a number of instrument anomalies were experienced this past year. MOPITT lost one-half of their spectral channels because of a cooler malfunction, later one of the chopper devices failed affecting two of the remaining MOPITT channels. Fortunately these channels are still able to collect data. Despite these problems MOPITT is acquiring high quality data for both carbon monoxide and methane. The MODIS instrument developed a power supply problem that shut down the instrument for two weeks. Changing to the redundant side electronics rectified the problem. MODIS has experienced no significant problems since this anomaly was resolved. The spacecraft sailed through a major Leonid meteor shower event with no problems.

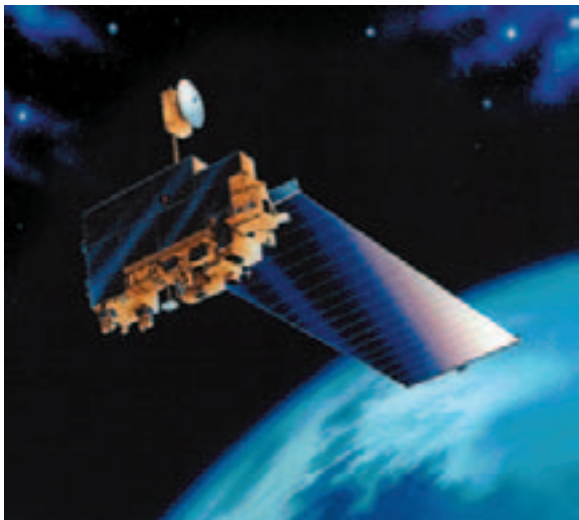
The year 2001 highlights include release of the MOPITT yearly carbon monoxide distributions, the CERES release of the first annual incoming and outgoing radiation flux products, and a MODIS release of portions of their consistent year data collection. The MODIS land rapid response team joined up with the U.S. Forest Service to develop a system that enables the Forest Service to monitor wild fires using Terra MODIS' direct broadcast capability. The USFS has installed the necessary hardware and software to capture MODIS data as Terra flies overhead. The down-link site, located in Salt Lake City, Utah provides coverage of most of the western U.S.

Many Terra science products were released during 2001. Public release dates and status of specific products depend on the complexity of the product and successful completion of calibration and validation. The early release, minimally-validated products are defined as "BETA", and are intended to enable users to gain familiarity with the parameters and the data formats. Since considerable time is required for full validation and quality assurance of scientific quality data, a partially validated or "PROVISIONAL" product can facilitate data exploration and process studies that do not require rigorous validation. "VALIDATED" products have well-defined uncertainties

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and are deemed suitable for systematic studies such as climate change, as well as for shorter term, process studies. They are also subject to continuing validation, quality assurance, and further improvements in subsequent versions. Users should keep in mind that EOS data products were designed with stringent accuracy requirements and developed with high standards for validation. This means that even Beta and Provisional products may be of higher quality than standard products available from heritage missions such as AVHRR. The scientific community is encouraged to use all levels of data products but to be mindful of the quality assurance flags provided with the data sets.

Terra product definitions and the status of Terra Data Products can be found on the internet at: http://eosdatainfo.gsfc.nasa.gov/eosdata/terra/terra_dataproduct.html



The Terra spacecraft, shown at left, was launched in December 18, 1999 and continues its mission to monitor the health of the Earth's Atmosphere, Oceans and Land.

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Earth System Science Pathfinder (ESSP)



A component of NASA's Earth Science Enterprise (ESE), the ESSP Missions are intended to address unique, specific, highly-focused scientific issues and provide measurements required to support Earth science research. Dr. Marc Imhoff of the Biospheric Sciences Branch is the Project Scientist for the ESSP Program.

The ESSP missions are an integral part of a dynamic and versatile program consisting of multiple Earth system science space flights. The ESSP program is characterized by relatively low to moderate cost, small to medium sized missions that are capable of being built, tested and launched in short-time intervals. In implementing these missions, the concept of Principal Investigator (PI) was adopted. The PI is responsible for all elements of the mission, from ensuring the science accuracy to making sure the mission stays on budget and on time. These missions

are capable of supporting a variety of scientific objectives related to Earth science, including the atmosphere, oceans, land surface, polar ice regions and solid Earth. Investigations include development and operation of remote sensing instruments and conducting research using data returned from these missions collected by these instruments. Subsequent satellite launches are planned over the next few years, all of them focusing on the atmospheric sciences.

The ESSP project scientist is responsible for helping the ESSP Program office review and monitor the progress of previously selected ESSP Missions, compose and release updated announcements for new missions, and aid in the selection of new missions. The ESSP Project scientist serves as the executive secretary on ESSP Review Panels.

This year in the ESSP Program the third Announcement of Opportunity was composed and released. A review panel for step I selections was convened and six missions were chosen to go forward into step 2:

- 1) Altimetric Bathymetry from Surface Slopes (ABYSS) Dr. Walter H. F. Smith, NOAA
- 2) AQUARIUS, Dr. Chester J. Koblinsky Goddard Space Flight Center
- 3) Earth Change and Hazard Observatory (ECHO), Dr. Jean-Bernard Minster, Scripps Institution of Oceanography
- 4) HYDROS: The Hydrosphere State Mission, Dara Entekhabi, Massachusetts Institute of Technology
- 5) The Orbiting Carbon Observatory (OCO), Dr. David Crisp, Jet Propulsion Laboratory
- 6) Thunderstorm Observations and Research Mission (ThOR), Dr. Hugh J. Christian, Jr., Marshall Space Flight Center

Also this year, attention was paid to getting ready for the first ESSP launch – the Gravity Recovery and Climate Experiment – GRACE (Figure 32). The GRACE Mission will be the inaugural flight of NASA's ESSP Program. GRACE is designed to make high resolution measurements of differences in Earth's gravity field. These measurements will allow for revolutionary insights into deep ocean currents and underground water reservoirs both of which are important in climate studies as well other resource oriented applications. Consisting of twin satellites flying in formation, GRACE will use SuperSTAR Accelerometers, a K-band Ranging System, a Star Camera Assembly, and a Black-Jack GPS Receiver and Instrument Processing Unit allowing for the precision measurements required to process the gravimetric data. GRACE will be launched from the Plesetsk Cosmodrome, a former ICBM site in northern Russia. This site has been one of the most active launch sites in the entire world. EurROCKOT GmbH is providing the launch vehicle. The booster unit is an adaptation of the highly reliable SS-19 ICBM tested in flight over 140 times. A newly developed multi-ignitable and highly maneuverable third stage BREEZE was added. The complete ROCKOT system including BREEZE has been proven in flight three times with a 100% success rate. The payload is assembled on site and then transported to a launch pad that has been modified to accommodate the ROCKOT launch vehicle. Plesetsk also provides telemetry and tracking services via the existing ground measurement infrastructure.

GRACE is a joint partnership between NASA in the United States and Deutsche Zentrum für Luft- und Raumfahrt (DLR) in Germany. The Principal Investigator is from University of Texas Center for Space Research and the Co-Principal Investigator is from the GFZ in Germany. NASA's Jet Propulsion Laboratory has responsibility for the Project Management and Project Science of GRACE. Goddard Space Flight Center maintains responsibility for Mission Management.

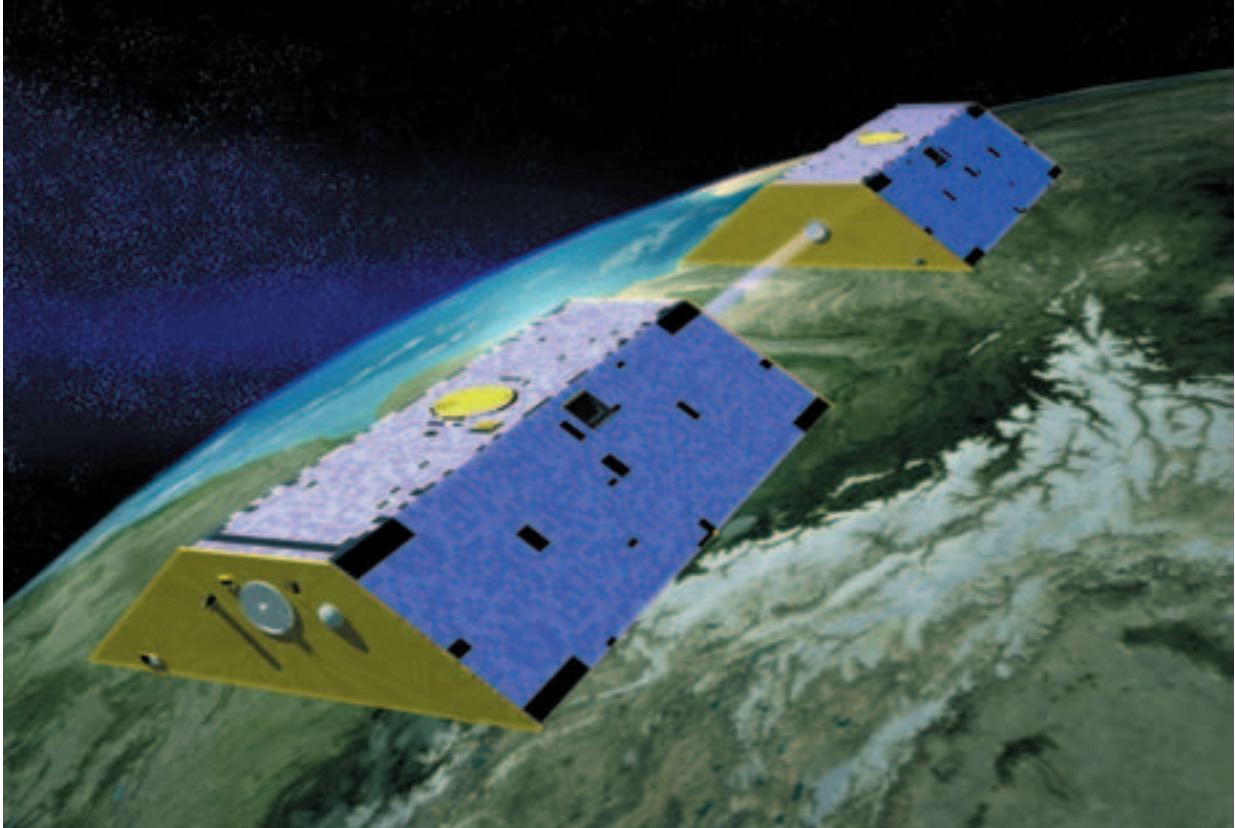


Figure 32: The two GRACE spacecraft will fly in co-planar orbits between 186 and 310 miles (300 and 500 km) above the surface at an inclination between 89 and 90 degrees. They will be separated along track by between 62 and 310 miles (100 and 500 km) – distance varies over the life of the mission. Orbit maneuvers will be required every 30-60 days in order to maintain the separation between the satellites in addition to occasional calibration and altitude “make-up” maneuvers. The mission is designed for a five-year lifetime.

For more information about GRACE visit the Web sites:

<http://www.csr.utexas.edu/grace/> and

<http://essp.gsfc.nasa.gov/>.

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Landsat 7 Science and Applications Users

Over nearly 30 years of observations, Landsat observations have found increasingly wide acceptance within the science and applications community. As one measure, the Science Citation Index records some 3200 peer-reviewed articles making use of Landsat data since 1972, with significant increases in these citations over time (Figure 33). These studies cover topics as diverse as land cover change, urban growth, agricultural production, grasslands productivity, forest state and biodiversity, water quality, archeology and anthropology, the geographic distribution of malaria, and volcanology. In fact, the use of Landsat data within the science community has spread through time. Early papers were largely confined to the remote sensing science community, and

often reported on promising, if hypothetical, uses of remote sensing. Today, Landsat has evolved to become a primary tool for addressing basic questions in the earth and social sciences. Dr. Darrel Williams, Associate Chief for Science within the Laboratory for Terrestrial Physics, is the Landsat Project Scientist.

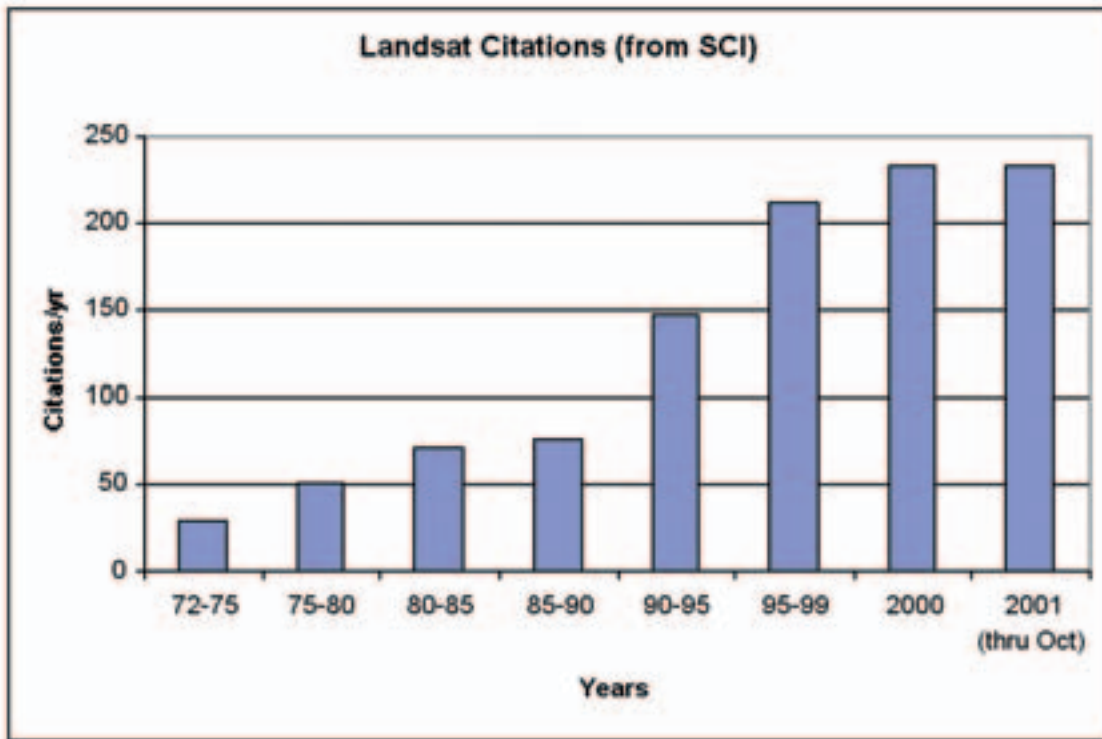


Figure 33. Peer-reviewed papers using Landsat data, from Science Citation Index

For science applications, Landsat observations fill an important niche between the highly-repetitive but coarse spatial resolution observations from the NOAA AVHRR, NASA EOS MODIS and French VEGETATION instruments and the ultra-high spatial resolution, local observatories such as the Space Imaging Corp. IKONOS instrument and the Digital Globe Quickbird sensor. Landsat provides systematic global coverage at a frequency sufficient to capture seasonal variations and at a spatial resolution where land cover dynamics, under the influence of natural processes and human activities, is clearly evident. If we are to link observed patterns of terrestrial global change to local environmental conditions and drivers (e.g. human populations), then Landsat-type observations are a fundamental requirement.

Landsat data have also become vital to the commercial and applications communities, based on advances in scientific understanding of these observations. Value-added resellers (VARs) produce a variety of land-cover information products for Federal agencies such as USDA, U.S. Forest Service, Census Bureau, Department of State and the Department of Defense as well as state and local governments, resource telecommunications and extraction companies, and agribusiness. Currently, there is estimated to be an annual market of ~\$200 million associated with the analysis and integration of Landsat data for value-added activities within the United States. Overseas, the International Cooperators feed foreign VARs with information products as well. At the Landsat Data Continuity Mission (LDCM) conference held in January 2001 in Reston, VA, the consensus among both science and industry was that Landsat data served as a “gateway” data product, introducing consumers to remote sensing at relatively low-cost, and paving the way for use of high spatial resolution commercial sources.

Capturing the Promise

The Landsat program innovated global-scale land cover monitoring by providing consistent, systematic, seasonal observations of all the Earth's continents. However the difficulties in using the large data volumes (multi-terabytes) and complexities of analyzing observations over a wide range of land-cover, seasonal, and atmospheric conditions, have continued to challenge the remote sensing science and applications communities.

The earliest studies (~1972-1982) to address the Landsat global potential included the NASA/NOAA/USDA Large Area Crop Inventory Experiment (LACIE) and the follow-on Agricultural and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS). These global scale studies were directed to evaluating first global wheat production (in LACIE) and then corn/soybeans in AgRISTARS. Because the data volumes were so large for computers of the day (typically IBM 360 mainframes with 0.5 to 2 megabytes of memory), the study scientists devised a statistical sampling strategy that would examine 100 km² (about 5% of a single Landsat scene) areas to judge regional growing patterns. In 1982 this technology was transferred to the US Department of Agriculture, where the basic analysis process is still used today, particularly by the Foreign Agricultural Service.

In the 1980's attention shifted to assessments of deforestation rates in the world's tropical forests. Growing concerns with human impacts on the Earth's carbon cycle in the 1970's and 1980's had led to the recognition that our knowledge of tropical forest patterns and their exploitation by human populations was quite limited and inaccurate. At first, most attention was focused on use of the NOAA Advanced Very High Resolution Radiometer (AVHRR) observations, which, despite their name are far coarser spatially (1.1 km) than Landsat (30 m). The first AVHRR-based estimates of tropical deforestation were far in excess of the rates reported by the individual countries (e.g., Brazil, Venezuela, Paraguay, etc). An initial comparison with Landsat-based analyses demonstrated that the AVHRR observations were simply too coarse to meet the needed area accuracy requirements. This led to the NASA-sponsored Landsat Tropical Deforestation Pathfinder effort in the mid-1990's. Unlike the LACIE/AgRISTARS program, computers were now big enough (typically UNIX workstations) to handle full Landsat scenes. Over approximately 6 years teams across the US handled, processed and analyzed in excess of 3000 Landsat scenes, in developing refined estimates of tropical deforestation.

The USGS took on a similarly scaled endeavor to map the United States Land Cover for 1990 under the Multi-Resolution Land Cover project. In this case multitemporal observations from the approximately 900 scene locations needed to cover the United States, were processed and analyzed to establish land cover trends for 1990 (Previous studies, in the 1970's had used U-2-collected aerial photography, visually interpreted by human analysts).

In the late 1990's NASA (and NIMA) selected the Earthsat Corp. (Rockville, MD), under the NASA Science Data Buy Program, to acquire and ortho-rectify a full global coverage of Landsat observations centered on 1975 and 1990. These observations would provide baseline information on land cover state and dynamics from the inception of the Landsat program, at approximately decadal time intervals. A similar activity has recently been undertaken for the year 2000 (see below), exploiting the much more robust data archive produced by Landsat 7 since it went operational in July 1999. This suite of multi-decadal global Landsat observations presents computational and scientific challenges thought to be insurmountable only a decade ago. Perhaps the greatest challenge is to find a land cover analysis and associated validation method, which is acceptable across the broad community of science researchers, involved in Landsat-based land cover change studies today.

Landsat

Background: The first Landsat satellite was launched in July, 1972. This event initiated the longest, *uninterrupted* coverage of the Earth, as seen from space, in the history of mankind. Given the unique combination of repetitive, multispectral global coverage at a spatial resolution where one can access changes in the landscape caused by both natural and anthropogenic activities, this 30-year archive of imagery provides an invaluable historical record of land use and land cover change world-wide. In essence, the archive of Landsat imagery is equivalent of having a periodically refreshed family photo album for the entire Earth. [See the *Education and Outreach* section for a more in-depth discussion of the history of the Landsat program.] Uses of Landsat data cover topics as diverse as assessing land cover change, urban growth, agricultural production, grasslands productivity, forest state and biodiversity, water quality, the geographic distribution of malaria, as well as studies in archeology and anthropology, and volcanology – to name just a few examples. Members of the Biospheric Sciences Branch have been major contributors to the success of the Landsat program throughout its history. Often working behind the scenes, Branch members have helped to establish the baseline requirements of the various missions, to ensure the scientific integrity of the multispectral measurements that were acquired, and to develop new ways to extract useful information from the data.

The images collected by the Landsat series of satellites during the first decade of the program were so intriguing that Congress acted to commercialize the program in the early 1980's. However, by the end of the 1980's it was quite obvious that this attempt to commercialize the program was failing, but not because of lack of interest in the data. The rapid advances in computing power throughout this period made it much easier to analyze these large data sets, but the cost and copyright protection placed on the data via the commercialization effort were major obstacles to its use. In 1992 Congress reversed its earlier decision by passing the Land Remote Sensing Policy Act, thereby returning the Landsat program to U.S. government control. NASA Goddard Space Flight Center was once again asked to play a major role in overseeing the design, build and launch of Landsat 7, and to take steps to ensure continuity of the program into the future, but at a lower cost to the taxpayer. Darrel Williams, who had served as Landsat Assistant Project Scientist during the build and launch of Landsat's 4 and 5 in the late 70's and early 80's was tapped to serve as the Landsat Project Scientist during this latest era.

Landsat 7 Pre-launch

Williams formed the Landsat Project Science Office (LPSO) in 1992, wholly within the Biospheric Sciences Branch, to maintain scientific oversight of the Landsat 7 mission. Jim Irons* has served as Deputy Project Scientist, John Barker as Associate Project Scientist, and Brian Markham as Calibration Scientist for Landsat 7. [*Jim Irons now also serves as the Study Scientist for the Landsat Data Continuity Mission (LDCM), slated for launch in the 2006 time frame; a status update on the LDCM is provided later in this section.] From the very beginning of NASA's role in Landsat 7, the LPSO acted to ensure the scientific integrity of the mission by helping to:

- specify the requirements for the system including the spacecraft, instrument payload, ground system, and data products;
- develop the operating concepts and plans;
- establish a robust strategy for capturing, archiving, and distributing data; and
- verify, both pre-launch and post-launch, system and instrument specifications and performance.

Landsat 7 Today

Landsat 7 was successfully launched on April 15, 1999, and it has been a tremendous success. There is every indication that the Landsat 7 mission has built upon the historic strengths of the Landsat program. The low cost of Landsat 7 data, as well as the elimination of data copyright, has fostered an environment in which users are free to experiment with novel applications, and use large quantities of data for existing applications. Technically, the improvements in Landsat 7 have proven a boon to researchers. It would take far too much time and space to summarize the various aspects of this mission, particularly the technical improvements to this mission relative to prior missions, that the LPSO was directly involved in. Suffice it to say, however, that members of the LPSO take great pride in the role that they have played in ensuring the success of this latest Landsat mission. Perhaps the following quote from Dr. Samuel Goward, Landsat Science Team leader from the University of Maryland, can provide a concise summary statement relative to the success of the Landsat 7 mission, with an underlying hint of the role played by the LPSO:

“Analyses and evaluations indicate that the data quality is outstanding, particularly with respect to radiometry, image geometry and geographic registration, and repetitive coverage of the global continental and coastal regions. [...] The Landsat 7 mission achieves both the promise conceived by early visionaries who designed this Earth land observatory as well as the experience and wisdom of scientists and engineers who have spent the better part of 30 years exploring its potential.”

LPSO Becomes Land Cover Satellite Project Science Office

The LPSO was renamed the Land Cover Satellite Project Science Office in FY'01 by Dr. Jack Kaye of NASA HQ to reflect the broader role of the individuals above in influencing the scientific integrity of NASA's higher resolution Earth observing missions, such as Landsat, EO-1, and LDCM. Dr. Kaye also felt that combining the science oversight activities for these common missions could minimize costs. For example, the LPSO group played a key role early on in defining and securing the Advanced Land Imager (ALI) and the Atmospheric Corrector device for the first NMP EO-1 mission. We have continued to work closely with EO-1 Mission Scientist, Steve Ungar, to coordinate activities, assist in the calibration of the ALI, and keep overall costs down by sharing computing facilities, etc. In summary, this group of individuals, plus a few others in the Branch and elsewhere in the Earth Sciences Directorate, constitute NASA's in-depth corporate memory of the past, present and future Landsat Program and NASA's higher resolution Earth observing missions.

Landsat 7 Post Launch Activities

Following the successful launch of Landsat 7, the Science Office has been responsible for:

- assessing and maintaining ETM+ instrument calibration (we also verify system and instrument specifications and performance for determining award fees to paid to instrument and spacecraft prime contractors),
- refining and/or developing new ETM+ radiometric assessment and correction algorithms,
- assessing the data acquisitions via the Long Term Data Acquisition Plan (LTAP) to ensure that a robust global archive of ETM+ data is being acquired,
- continuing the development of educational outreach packages for Landsat,

- managing the Landsat Science Team grants (now expired), and
- working with the NASA management to derive an acceptable LDCM mission plan.

Additional information about some of these activities is provided in the remainder of this Landsat section.

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Landsat Calibration

There are two Landsat satellites currently operating: Landsat-5, launched in 1984 and Landsat-7, launched in 1999. Each satellite provides moderately high-resolution imagery of the Earth. This imagery is widely used to monitor land use and land cover conditions on the Earth's surface. Both satellites were being operated by the United States Geological Survey (USGS) at the end of 2001, though each had been developed and launched by NASA. NASA retains a role in the calibration of data acquired by the instruments on each satellite, the Thematic Mapper (TM) on Landsat-5 and the Enhanced Thematic Mapper Plus (ETM+) on Landsat-7.

Data from each of these satellites are received at the USGS EROS Data Center (EDC) in Sioux Falls, SD. The data are archived and available for purchase by the general public. When ordered, the data are retrieved from the archive, radiometrically and geometrically corrected, that is, converted to a form that is directly relatable to an absolute measure of the energy reaching the sensor from the earth and to an absolute location on the surface of the earth.

Working with the USGS and in particular the Image Assessment System (IAS) portion of the Landsat-7 Ground System, the goal of this effort is to maintain and improve, to the extent possible, the radiometric and geometric accuracy of the data products provided by the Landsat processing systems. In addition the radiometric and geometric status of the instrument and data products are monitored and trended.

Significant changes during 2001 included:

- Termination of the Landsat-7 science team, a portion of which had contributed significantly to the radiometric performance and calibration of the ETM+ instrument
- NASA funding of a proposal to continue the radiometric performance and calibration efforts previously covered under the science team

Recent results:

The radiometric calibration of the Landsat-7 ETM+ reflective bands is accurate to 5% and is changing by less than 1.5%/year.

The radiometric calibration of the Landsat-7 ETM+ one thermal band is accurate to 1-2% and is stable.

A set of recommended calibration equations were developed to calibrate the Landsat-5 TM reflective bands based on its one on-board calibration device and ground based measurements. After refinement, these equations will be provided to the ground processing system for Landsat-5 TM data. Previously the calibration had been solely based on the internal calibrator, which has degraded over the years and was not calibrated as well as the Landsat-7 ETM+ to begin with.

Preliminary analysis of data from the one thermal band on Landsat-5 TM showed accuracy at about the 2% level, some of which may be a bias.

A number of parameters were adjusted within the data processing files to improve the quality of the calibrated products, these include destriping parameters, calibration data extraction windows, geometric correction parameters, and image sharpening parameters

Without these efforts to calibrate the data, most of the applications to be summarized in the following sections would not be possible, or at a minimum, they would have reduced scientific value.

Cooperating Organizations/personnel:

NASA/GSFC- B. Markham, J. Barker, J. Barsi, E. Kaita, J. Miller, J. Sun (D. Williams)

USGS/EDC – J.Storey (stationed at GSFC), P. Scaramuzza, J. Christopherson, R. Hayes

Canadian Center for Remote Sensing (CCRS) - Phil Teillet (on sabbatical at GSFC FY 2000)

NASA HQ Code Y

NASA/JPL – F. Palluconi

South Dakota State University – D. Helder

University of Arizona – K. Thome

Rochester Institute of Technology – J. Schott

Contact: Brian Markham, Brian.L.Markham.1@gsfc.nasa.gov

Landsat Science Results

The sections below highlight a few of the interesting programs and projects that explored the Landsat-7 mission in recent years.

Landsat-7 Science Team

The NASA Landsat Science Team, selected in 1996, provided science guidance to the Landsat-7 Project Science Office at NASA GSFC concerning development and deployment of the mission as well as pursuing advances in the use of Landsat-7 data for global change research. The Landsat Science Team activities ended in June 2001. Much of the Landsat Science Team research has been summarized in the October 2001 Landsat 7 special issue of *Remote Sensing of the Environment* (Vol. 78, Issues 1-2). Some highlights of this activity include:

Landsat 7 Long-Term Acquisition Plan: Terry Arvidson, John Gasch and Sam Goward report of the development and use of the innovative Landsat 7 Long-Term Acquisition Plan (LTAP). This is a new concept in the history of the Landsat mission, in which an automated process, based on historical land cover information and cloud cover statistics, combined with current cloud cover forecasts, provides a systematic process to acquire comprehensive global observations from Landsat, as cloud-free as possible. The results to date have been exceptional, with better than 90% of all the Earth's land areas viewed with less than 10% cloud in less than one year. This approach substantially enhances the value of Landsat 7 for global-scale studies because, for most

sites, the high-quality, multi-temporal, seasonal observations needed to carry out effective land cover characterization, are systematically being acquired by the observatory.

Landsat 7 Characterization: Several papers in this special issue cover the radiometric (Thome, Teillet, Vogelmann, Hu, Schott, Masek) and geometric (Vogelmann, Masek) characteristics of the Landsat 7 observing system. In all cases the Landsat 7 is both better than equivalent attributes on Landsat 5 and, in many cases, better than the specifications laid down for the system during design and construction. For example the radiometric performance exceeds pre-flight specifications by up to a factor of two and geographical positional accuracy is up to 5 times better than specified, after the USGS applies post-orbital pass information on satellite positioning. These results demonstrate the value of the attention that the Landsat Science Team and the NASA/USGS Project Science Office paid to development of the Landsat 7 mission.

Atmospheric Corrections: Studies by Susan Moran, et. al., Robert Cahalan, et. al. and Chuanmin Hu, et. al. demonstrate that because of the high quality radiometry in Landsat 7 observations, it has now become easier to relate these satellite measurements directly to ground conditions (surface reflectance and surface-leaving radiance), effectively reducing the impact of variable atmospheric conditions. These studies hold the promise that in future missions these unwanted variations in satellite remote sensing measurements may be substantially removed.

Mid-latitude Forest Cover Change: Building upon the Tropical Deforestation research carried out in the 1980's, Curtis Woodcock and his team at Boston University, in conjunction with Warren Cohen (Oregon State University) have developed multi-scene analysis procedures which would permit continental to global-scale analyses of mid-latitude deforestation rates. These rates for some locations may be higher than in the tropics. On the other hand recent studies of the Earth's carbon budget suggest that the northern hemisphere forests may currently be serving as at least a short-term sink for atmospheric carbon (placed there primarily by fossil fuels consumption). The methods demonstrated by Dr. Woodcock and his team provide the knowledge and tools needed to address these uncertainties about mid-latitude forest dynamics.

Agricultural and Grasslands Productivity in Semi-arid Environments: Dr. Susan Moran (USDA, Tucson, AZ) and her research team have combined Landsat observations with other remotely sensed measurements and models of plant growth to track the seasonal evolution and annual productivity of irrigated agricultural fields and rain-fed grasslands in southern Arizona. They show that the Landsat observations provide critical information on the state and dynamics of vegetation canopies in these systems, which permits accurate assessment of plant growth in these water-limited environments.

Coral Reef Monitoring: Coral reefs are called the "rainforests" of the ocean, in that they host tremendous concentrations of marine biodiversity. Drs. Serge Andrefouet and Frank Muller-Karger (U. South Florida) have been monitoring the Carysfort Reef in Florida, the largest reef in the Florida keys. Their findings indicate that only 5% of the coral in the Carysfort Reef is left alive, a decrease from more than 50% in 1975. Landsat-7 is allowing the structure and extent of coral reefs to be monitored globally for the first time, and more than 5000 coral reef images have been acquired worldwide since launch.

Antarctic Icebergs: Dr. Robert Bindaschadler (NASA GSFC) has been using Landsat-7 imagery to map the velocity field of icestreams in Antarctica. On January 16 Bindaschadler, during his daily review of new Landsat 7 images of Antarctica, noticed a striking feature on the Pine Island Glacier: a thin crack more than 25 kilometers (15 miles) long, stretching more than two-thirds of the way across the glacier. This new feature, not present on earlier imagery, suggests that a new "super iceberg" will calve from Antarctica during early 2002. These large icebergs can present a hazard for shipping in the Southern Oceans, and reveal important information on the environmental conditions on the ice cap.

High-Plains Sand Dune Reactivation: Dr. Alexander Goetz (U. Colorado) has been focusing on the potential reactivation of Holocene sand dunes in the Western High Plains. During periods of drought (such as the 1930's Dust Bowl) these dunes can be stripped of their plant cover and rapidly erode, harming the agricultural productivity of the region. Goetz has assembled a GIS-based model, using land-cover derived from Landsat-7 imagery, and measured precipitation and wind fields, to create maps showing the locations where sand dunes may be reactivated during drought.

NASA Land-Cover Land-Use Change (LCLUC) Program

The LCLUC program funds research on global land-cover change, including studies on the socio-economic and climate drivers for change. Associated studies have also concentrated on developing methods for analyzing remotely sensed data, and initiating pilot programs for the Global Observations of Forest Cover (GOFC) project, which is attempting to map the world's forests. Landsat data is widely used by LCLUC investigators, at a variety of scales. While some investigators are looking in detail at changes occurring in a local region, and increasing number are expanding their studies to encompass entire countries and regions. Recent applications of Landsat include:

Carbon Fluxes in the Miombo Woodlands: Dr. Paul Desanker (U. Virginia) is using Landsat-5 and Landsat-7 data in order to create regional estimates of carbon pools and carbon fluxes for the Miombo Woodlands of Southern Africa. This dry tropical region is subject to both natural disturbance (fire cycles) as well as forest clearing by humans. By combining multi-temporal Landsat data (detailing land-cover changes) with carbon accounting models, Desanker is producing the first regional assessment of carbon balance for the region.

Rates of Land-Cover Change in the United States: Dr. Tom Loveland (USGS) is studying the spatial and temporal dimensions of contemporary U.S. land use change by sampling 84 U.S. ecoregions with 20x20km blocks of multitemporal Landsat data (1973-2000). Initial results indicate that while the driving forces for land-cover change vary from place to place, similar drivers may have different consequences in different regions. Over the last 30 years, Loveland has found areas of land-cover conversion varying between 13% for the Southeastern Plains to just 3% for the Northern Piedmont.

Amazonian Forest Degradation Mapping: Much of the biomass removal from the Amazon rain forest may occur as "canopy degradation", that is the removal of individual trees through species-specific logging, rather than as clear-cutting. Dr. David Skole (Michigan State University) has developed spectral unmixing techniques to quantify canopy degradation using Landsat data, and has applied these methods to a time series of Landsat-5 and Landsat-7 data from the 1980's and 1990's. Skole finds considerably less area of degraded canopy than previously estimated by limited ground sampling.

Solid Earth/Natural Hazards

The NASA Solid Earth/Natural Hazards program funds basic investigations into solid earth geodynamics, geology, and geomorphology, as well as applied work on predicting and mitigating natural hazards. Landsat data is commonly used by this research community, often in combination with other data sources such as GPS, interferometric radar, and seismologic data.

Bhuj Earthquake: On January 26, 2001, a magnitude 7.6 earthquake struck the Indian province of Gujarat, killing nearly 20,000 people and injuring over 160,000. A neotectonics team from

Columbia University, San Diego State University, and University of Nevada-Reno was quickly dispatched to the epicenter to map surface ruptures and measure fault displacements. The team relied on merged SRTM digital topography and Landsat-7 ETM+ data supplied by Robert Crippen (JPL) in order to locate the fault trace and put the local geology into context. The team mapped numerous liquefaction and local slumps, although there was little surface evidence of fault rupture.

Mt. Etna Eruption: During July and August 2001, Mt. Etna (Sicily) experienced its most sustained eruption in a decade. A variety of satellite sensors, including Landsat-7, captured the daily and weekly evolution of the event. Using Landsat-7 data, the thermal development of lava plumes and hotspots could be tracked and measured. Using data such as these, Drs. Luke Flynn, Andrew Harris, and Rob Wright (U. Hawaii) are calculating lava effusion (volume flux) rates from Mt. Etna and other active volcanoes. Trends in these data can indicate changes in the style of magmatism, or long-term changes in eruptive capacity.

National and International Programs

In addition to individual science investigations, projects within the U.S. and overseas have been set up to use large volumes of Landsat-7 data for specific tasks. These projects encompass processing and analysis flows larger than those that can be easily handled by individual scientists.

Year 2000 Data Buy: In order to facilitate interannual comparisons and large-area analysis of Landsat data, NASA has sponsored a series of Landsat Data Buys through the Stennis Space Center and the Earth Satellite Corporation. The first (1998-2001) resulted in the creation of the GeoCover product, a global dataset of about 7000 orthorectified Landsat-5 images centered on the year 1990, together with an RGB mosaic useful for visual interpretation and educational uses. Following the success of this project, NASA awarded a second data buy contract to the Earth Satellite corporation last year to produce a Year 2000 Landsat-7 orthorectified global dataset. Planning for this product is underway now, with product delivery expected in 2002-2003.

Millennium Ecosystem Assessment: As part of the United Nations Environment Program (UNEP), an international consortium is working to produce the first integrated assessment of the status of the world's ecosystems. The overall assessment will include component assessments undertaken at several different geographic scales, ranging from individual villages to the globe, and the process will be designed so that the findings at any given scale are informed by the assessment components undertaken at other scales. In September 2000, President Clinton stated to the U.N. Security Council that the United States would commit support to the Millennium Ecosystem Assessment process with data from its TERRA, SeaWifs and Landsat satellites. (These data have been valued as an in-kind contribution of some \$60 million.). The Year 2000 Data Buy (above) will also help to satisfy this commitment. In October 2001, a workshop on "Remote Sensing and the Millennium Ecosystem Assessment" was held to discuss technical approaches for collecting and analyzing satellite data for this important activity.

NASA Climate Change Initiative: In order to help the nation understand, predict, and mitigate future climate changes, President Bush has pursued an interagency Climate Change Initiative. Workshops held during 2001 to outline NASA's contribution focused attention on the need for repeated land-cover analysis, in order to quantify land-atmosphere carbon fluxes related to land-cover conversion and natural disturbance (e.g. fire, insect damage, etc). While plans are still being formulated, there is a clear consensus among participating scientists that Landsat-7 data will form the basis for North American land-cover change assessments and carbon accounting models.

Australia National Carbon Accounting System: The Australian Greenhouse Office devised the National Carbon Accounting System (NCAS) in 1997 to provide an accounting system for

sources and sinks of greenhouse gas emissions from Australia, in order to meet international standards and treaties. Following serious consideration of sampling alternatives, the decision was made two years ago to base the system on a full inventory, modeling carbon at a hectare scale building on Landsat data from 1972 in ten time slices to Year 2000. A Y2K continental mosaic has been constructed from ETM+ data and earlier scenes are being registered and calibrated against this. Completion is expected by early 2002. A site specific carbon model (FullCAM) is used to estimate total landbased carbon fluxes over the 28 year period for each 25 meter pixel.

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Landsat Data Continuity Mission (LDCM)

Significant progress was finally made in 2001 towards the formulation of a follow-on mission to Landsat 7, currently called the Landsat Data Continuity Mission (LDCM). Landsat 7 was launched on April 15, 1999 as a traditional government-owned and government-operated satellite system. NASA's partner in Landsat Program Management, USGS operates the satellite as a scientific mission for global land observations. The on-going government mission has been a great success, but Congress has directed NASA and USGS to conduct the follow-on LDCM through a data buy from a privately-owned and privately-operated satellite system in an effort to further the commercialization of land remote sensing. Even in this context, the global observation of land cover and land use change remains as the principal scientific objective of the LDCM. Dr James Irons of the Biospheric Sciences Branch, acts as LDCM Study scientist.

NASA has struggled for the past few years to develop an effective data acquisition strategy for the LDCM. The greatest challenges are to procure data meeting LDCM scientific requirements at a reasonable cost and in a time frame ensuring continuity with data from Landsat 7. Early market research indicated that no current or planned commercial remote sensing satellites would be capable of providing data fully meeting LDCM requirements. Consequently, the need for NASA and USGS to partner with private industry became obvious. During 2001 NASA settled on an acquisition strategy developed at GSFC in cooperation with Stennis Space Center and the USGS. The strategy is now leading towards a government/industry partnership with LDCM data acquisition beginning in March, 2006, before the predicted end of Landsat 7 mission life.

The first step in developing the data acquisition strategy was to specify the quantity and quality of data required from the LDCM. The LDCM study science team at GSFC led the drafting of an LDCM Data Specification in 2000 with significant contributions from Stennis Space Center and USGS. A public workshop was held on January 9 – 10, 2001 to review the draft specifications and to openly solicit comments on the data buy approach for the LDCM. Participation was solicited from the full scope of the Landsat program stakeholders including scientists, aerospace industry representatives, value added vendors, other federal agencies, and resource managers. The participants made clear that the commercial market for Landsat-like data (that is, data with a spatial resolution circa 30 m) was insufficient to garner totally private funding of an LDCM system. The participants, however, also emphasized the public good of the Landsat program and encouraged NASA and USGS to urgently formulate a strategy for ensuring data continuity beyond Landsat 7.

The workshop was followed by the appointment of a full-time LDCM Project Formulation Manager at GSFC. He quickly proposed a two-step procurement process centered around the Data Specification and a Data Policy. The first step consists of procurement of formulation studies, possibly from multiple contractors. The studies are intended to provide both a preliminary design for a privately owned LDCM satellite system and the definition of a viable partnership between government and industry. The second step consists of a down select to a single private partner that will build and operate the LDCM system. The LDCM Data Specification describes

the data required from the private system, while the Data Policy defines the government and commercial rights to the acquired LDCM data and data products.

Events rapidly followed the acceptance of this two-step approach by NASA and USGS management. A second public workshop was held in April to introduce procurement expectations and to discuss revisions to the Data Specification. The LDCM formulation team then set to work on the documents required for a request-for-proposals (RFP) for formulation studies. A draft RFP was released in early August with comments solicited from both private industry and the science community. Private meetings were held with several potential bidders at the end of August and a Pre-Solicitation Conference was conducted in October. A multitude of comments were received, reviewed, and addressed leading to the release of a final RFP on November 01. Proposals were due on December 19 and are currently under evaluation. The schedule calls for the selection of formulation phase contractors in early Spring 2002 with preliminary design reviews planned for Fall 2002. The reviews will be followed by an RFP for an LDCM implementation contract with selection in early 2003. The ultimate goal is to operationally procure LDCM data by March, 2006.

LTP scientists are integral participants in the LDCM. They led the development of the LDCM Data Specification and were instrumental in establishing the LDCM Data Policy. They organized the public workshops and have contributed to all of the tasks and activities leading to the recent release of the RFP for formulation studies. They will remain involved in all aspects of the LDCM with the goal of ensuring continuity of the Landsat scientific mission through the LDCM data buy. They must ensure that well-calibrated, high-quality LDCM data are available at a reasonable cost to all those who observe, study, and manage the Earth's land resources over time.

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Field Campaigns

Branch personnel over the past ten or more years have taken on management or coordination roles in major field campaigns. These field campaigns involve interdisciplinary scientists from NASA, other federal agencies, universities, and international partners performing in-depth research into various ecosystems such as grassland prairies in Kansas (FIFE), northern hardwoods in Maine (FED), and boreal forest in Canada (BOREAS). Web sites: <http://boreas.gsfc.nasa.gov/> and <http://fedwww.gsfc.nasa.gov/>.

Below are two such present activities, LBA (tropical forest in Amazonia) and SAFARI/SAVE (semi-arid savanna in southern Africa).

Large-Scale Biosphere Atmosphere Experiment in Amazonia (LBA)

The Large-Scale Biosphere-Atmosphere Experiment in Amazonia or LBA Project is led by the Ministry of Science and Technology in Brazil and currently includes two components, LBA-ECO and LBA-HYDROMET, which are managed within the Biospheric Sciences Branch. A formal agreement with Brazil initiated the field component of the LBA-ECO Project at the end of 1999 when infrastructure within the "legal" Amazon began to be established. The year 2001 brought the broad range of implementation activities within the Amazon to maturity, such that the second full season of field data collection activities were accomplished successfully; and the data and information systems became fully operational for supporting data analysis and modeling for the entire LBA Project of more than 100 scientific investigations. All necessary infrastructure and logistics support facilities and operational support personnel and mechanisms were put in place in accordance with the operating international agreements between the U.S. and Brazil and were

fully functional by the end of 2001, which completed Phase I of LBA. Selection of investigators for the second 3-year Phase II research is currently being solicited. A formal Implementing Arrangement for the LBA HYDROMET Project was not completed as hoped by the end of 2001, but the eleven HYDROMET science teams are making good progress through modeling studies and ground and satellite data analyses.

Excellent scientific progress has been made in all four areas of LBA ecological research, which include Land Use and Cover Change, Carbon Dynamics, Trace Gases and Aerosols, and Nutrient Dynamics and Surface Water Chemistry. In studies to investigate the rates of conversion and abandonment over the full Brazilian legal Amazon and much of the Ecuadorian Amazon, researchers have used government census data within Brazil and in other countries to link land cover data and land use data. Case studies are providing the basis for development of quantitative models of land use change. Some progress has been made in understanding the extent of logging, although the results are hotly debated. LBA is poised to make a major contribution to our understanding of the overall impact of logging on Amazonian ecosystems. Future scenarios of regional development and its impacts have already been generated.

Recent results with atmospheric inversion models admit the possibility of strong interannual variation in flux of carbon from the Amazon region. Regional scale ecological models driven by meteorological and/or satellite vegetation index data show that interannual weather variations can generate a strong signal in the carbon balance of the Amazon region. Tower-based eddy covariance flux studies at LBA's Santarém site in undisturbed forest, logged forest, and pasture have made it increasingly clear that tower-based carbon flux estimates are subject to considerable uncertainties during nighttime in the tropical forest environment in the Amazon.

NASA's trace gas and aerosol studies are focused on illuminating processes and reducing uncertainty, rather than producing definitive budgets, and these efforts are strongly complemented by those of Brazilian- and European-sponsored atmospheric chemistry research in LBA. For both local and mesoscale basins, there are now strong indications that changing land use has a significant impact on surface water chemistry. The grants for NASA's Phase I investigators were extended for 6 to 12 months late in the year. This decision was coupled with the Brazilian governments authorization to NASA to release the Phase II NRA in mid-December. These two actions will permit NASA-funded researchers to continue field measurements, including the initiation of NASA airborne campaigns in the Fall of 2002 to complement satellite and field data. These airborne missions will help to address gaps in knowledge of the Amazon functioning that have been highlighted in Phase I.

Web site: <http://lba-eco99.gsfc.nasa.gov/lbaeco/>

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Southern Africa Regional Science Initiative (SAFARI) 2000 and the Southern Africa Validation of EOS (SAVE)

The Southern African Regional Science Initiative - SAFARI 2000 - is an international science initiative aimed at developing a better understanding of the southern African earth-atmosphere-human system. Specifically, SAFARI 2000 was designed to identify and understand the relationships between the physical, chemical, biological and anthropogenic processes, which underlie the biogeophysical and biogeochemical systems of southern Africa. Particular emphasis is being placed upon biogenic, pyrogenic and anthropogenic emissions, their transport and transformations in the atmosphere, their influence on regional climate and meteorology, their eventual deposition, and the effects of this deposition on ecosystems. To accomplish this, participants

- integrate remote sensing, computational modeling, airborne sampling and ground-based studies;
- link the biological, physical and chemical components of the regional ecosystems by integrating them within the semi-closed atmospheric gyre persistent over the region
- combine the expertise and knowledge base of regional and international scientists.

SAFARI combines both ongoing long-term measurements with episodic field campaigns (see Table 3). The most extensive of these was the Dry Season 2000 campaign, in which several aircraft (including NASA's high altitude ER-2 with Terra instrument simulators) flew extensively in the region. Dr. Jeff Privette of the Biospheric Sciences Branch serves as a member of the SAFARI 2000 Steering Committee.

Table 3. SAFARI Intensive Field Campaigns (IFCs)

Period	Season	Primary Goal
August-September, 1999	dry	Air and ground characterisation of Mongu and Skukuza field sites; instrument shipping and deployment in region.
February-March, 2000	wet	Characterisation of vegetation structure, optics, and functioning at peak biomass along Kalahari Transect (precipitation gradient).
August-September, 2000	dry	Assess dynamics of dry-season emissions from biomass burning and other sources; Fire fuel load and remote sensing relationships; Major airborne activities.
December, 2000	wet	Characterisation of vegetation structure and optics at peak biomass over Miombo transect (soil gradient).

The simultaneous launch of NASA's Earth Observing System (EOS) Terra satellite with SAFARI 2000 has led to extensive synergistic interactions. Specifically, Terra initiated a new era in satellite remote sensing with the operational generation of many new global products. Science based on these products requires that product errors be quantified and documented (i.e., validated) throughout mission lifetimes.

The SAFARI region is probably one of the best for comprehensive EOS validation due to its unique natural features. Key to these is the massive Kalahari sandsheet, a 2.5 million km² basin of similar sandy soils extending from Zambia south through S. Africa. The sands are subjected to a large precipitation gradient (>1000 mm/yr. in the north to <400 mm/yr. in the south). The resulting vegetation gradient (woodlands to open low shrub savannas, respectively), combined with the relatively uniform flat background, provides an ideal testbed for understanding EOS algorithms. Further, the nutrient-poor sands lead to less palatable vegetation and hence less grazing. When the yearly grasses die off during the annual dry season, they become ready tinder for widespread fires. The fires, in turn, produce extensive aerosols and trace gas emissions (e.g., CO, CO₂ and chemical successors such as ozone), and provide extensive condensation nuclei for cloud formation, all estimated through EOS algorithms.

The Southern Africa Validation of Earth Observing System (SAVE-EOS; <http://modarch.gsfc.nasa.gov/MODIS/LAND/VAL/terra/privette>) was initiated in 1998 to validate Terra's products in association with the Terra instrument teams by augmenting and leveraging existing scientific capacity and programs in southern Africa (e.g., SAFARI 2000). SAVE has focused on a wide range of land (e.g., leaf area index, albedo) and atmospheric (e.g., aerosol optical depth, ozone) products. In practice, SAVE personnel have participated in each of the SAFARI major campaigns, and continue to sample key variables at two sites: Skukuza, South Africa (*acacia/combretum* woodland savanna) and Mongu, Zambia (Kalahari woodland). The project erected an above-canopy tower (climb-up) at each site for ongoing canopy-level measurements (Figure 34). Eddy covariance systems, including infrared gas analyzers for CO₂ flux measurement, were also deployed. As of January 2002, SAVE-funded investigators have submitted or published

more than 40 papers (about half in peer-reviewed journals) and provided more than 50 presentations at scientific conferences and workshops based on their SAVE/SAFARI work (Figure 35).

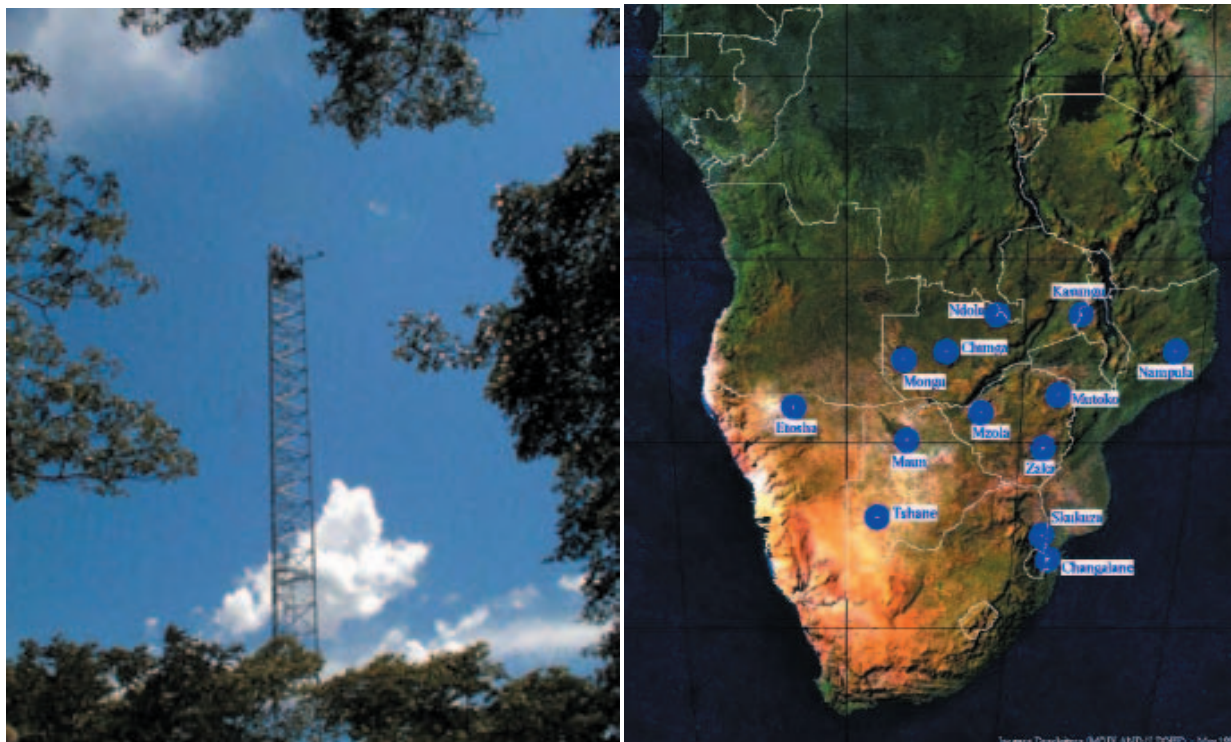


Figure 34 (left). SAVE's 33m tower in Kalahari Woodland, Mongu Zambia.

Figure 35 (right) Map of Africa showing sites.

Web sites: <http://safari.gecp.virginia.edu>

and <http://modarch.gsfc.nasa.gov/MODIS/LAND/VAL/terra/privette>

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2001 Refereed Publications

The Laboratory's publications for the year 2001 are listed in the various discipline sections. The total number of our refereed publications that actually appeared in print in 2001 was 112 (i.e., this does not include papers that were "accepted" and/or "in press"). This figure includes refereed journal articles, book chapters, and/or books authored by our civil servants, post doc's, visiting scientists, contractors, and people from other agencies co-located in our physical space who conduct joint research with us. The 58 publications in Biospheric Sciences are listed below.

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Campbell, Petya Entcheva. NRC Post Doctoral Research Associate, Biospheric Sciences Branch, "High spectral resolution remote sensing for forest damage assessment", February 6, 2001.

Eckhardt, Holger, "Kruger National Park - Management and Research", July 27, 2001.

Georgieva, Elena , Georgetown University, "Optical Characterization Methods", August 15, 2001.

Gunnarsson, Bjorn, Director Environmental Research Institute of Iceland, "Research in Iceland: The role of the Environmental Research Institute (ERI) in international research collaboration", March 2, 2001.

Hall, Forest , "The Carbon Initiative", May 8, 2001.

Huemmrich, K. Fred, Joint Center for Earth Systems Technology, University of Maryland Baltimore County (JCET, UMBC), "Remote Sensing of Arctic Tundra Carbon Balance", August 7, 2001.

Imhoff, Marc , Ecosystem Analysis and Radar Technology, Biospheric Sciences Branch, "Remote Sensing and the Kyoto Protocol - A Review of Available and Future Technology for Monitoring Treaty Compliance", October 9, 2001.

Irons, J.R. First Landsat Data Continuity Mission (LDCM) Workshop, USGS Headquarters, Reston, VA, Jan. 09 – 10, (Organizer and Presenter)

Irons, J. R. EOS Investigators Working Group Meeting, Ft. Lauderdale, FL, Jan. 29 to Feb. 01, (Presenter)

Irons, J. R. NRC Workshop on the Commercialization of Remote Sensing, National Academy of Sciences Building, Washington, DC, March 27 - 28 (Panel Member and Presenter)

BIOSPHERIC SCIENCES

Irons, J. R. Second Landsat Data Continuity Mission (LDCM) Workshop, St. Louis, MO, April 23 – 24 (Organizer and Presenter)

Irons, J. R. ASPRS 2001 Annual Meeting, St. Louis, MO, April 26 (Session Chair and Presenter)

Irons, J. R. Landsat Science Team Meeting, Honolulu and Hilo, HI, May 22 – 26 (Presenter)

Irons, J. R. EOS Investigators Working Group, San Antonio, TX, Oct. 30 to Nov. 01, 2001 (Presenter)

Irons, J. R. Landsat Data Continuity Mission (LDCM) Pre-Solicitation Conference, Linthicum, MD, Oct. 24, 2001 (Presenter)

Irons, J. R. Landsat Ground Station Operators Working Group, Orlando, FL, Nov. 12 – 15 (Presenter)

Irons, J. R. Land Cover Land Use Change (LCLUC) Science Team Meeting (Tropical Forest Investigators), University of Maryland, College Park, MD, Nov. 19 – 21 (Presenter)

Markham, B.L. Second LDCM Workshop, April 23-24, 2001, St. Louis, MO, Presented LDCM spectral bands and radiometry portions of the data specification

Markham, B.L. Landsat Science Team Meeting, May 21-28, 2001, Honolulu, HI. Presented Landsat-7 radiometric calibration update IGARSS 2001, Sydney, Australia.

Masek, Jeffrey G., Using Landsat Data in Global Assessments: Application to Forest Dynamics and Carbon Fluxes", March 13, 2001.

Middleton E.M. Forestry Conference, IUFRO, July 11-18 2001, Portland, OR. Presented "Seasonal and Canopy Strata Variations in Hyper-spectral Optical Properties of Foliage in Aspen Stands".

Middleton E.M. Program Planning Workshop, on a proposed new program "Vegetation Effects Environmental Sensing" (VEES), sponsored by the Defense Threat Reduction Agency (DTRA), October 4, 2001, Alexandria, VA. The NASA/USDA Fluorescence Team provided one of the nine invited presentations on existing and emerging "stand-off" technologies that could be further developed for finding land mines and/or ameliorating the toxicity of either land mines or biological/chemical agents. This was the first of several planning meetings held during 2001 to assist DTRA in developing an innovative research program to be initiated in FY'04.

Patil, Ganapati P. , Professor of Mathematical Statistics, and Director of the Center for Statistical Ecology and Environmental Statistics within the Department of Statistics at the Pennsylvania State University, "Multiscale Advanced Raster Map Analysis System: Definition, Design and Development", December 3, 2001.

Tucker, Compton James .Senior Earth Scientist, Biospheric Sciences Branch, "Remote Sensing at Troy (Trojan Horse Troy)", October 12, 2001.

Turner, Brian ,Reader, School of Resources, Environment and Society, The Australian National University, Canberra, Australia, "Australia's National Multitemporal Landsat Land Cover Database for Carbon Accounting", November 15, 2001.

Ungar, Steve, EO-1 Mission Scientist, "Can you do that?! The EO-1 Story", April 10, 2001.

Proposals

Three years of funding (FY'02-'04) was successfully obtained in August 2001 under the NASA Terrestrial Ecology Program, for a proposal reduced in scope from the original version submitted to the Carbon Cycle Science NRA in December 2000, entitled "Determining Photosynthetic Efficiency and Carbon/Nitrogen Cycling in Vegetation using Active and Passive Fluorescence Techniques" (PI, E.M. Middleton). The reduced scope eliminated the participation of Co-Investigators at NASA/Stennis and the University of New Hampshire, as well as some of the tasks proposed for the core activities of the GSFC and USDA team.

Student Aerosol Measurements for the Baltimore Asthma Project. B. Holben and E. Levine (\$30K), DDF

"Biotic Prediction: Building the HPCC Infrastructure for Public Health and Environmental Forecasting" selected through CAN-00-01-OES-017, the Computing Technologies project, formerly known as the HPCC Earth and Space Sciences project. PI is John Schnase (Code 930). Co-investigators are at NASA's GSFC (Code 930, 935, 920, 922, and 923 – Jeff Pedelty), USGS, and Colorado State University. Total funding is ~ \$1M over three years.

"A VLA Q-band Search Strategy for Interstellar Glycine" selected by the National Radio Astronomy Observatory. PI is Mike Hollis (Code 930) and co-investigators are at NASA's GSFC (Code 923 –Jeff Pedelty), NRAO, U. Chicago, and U. Illinois. Approximately 58 hours of observing time was granted on the Very Large Array for this astrobiology investigation, but the NRAO does not provide funds.

Landsat Radiometric Calibration: Towards a 20-Year Record of Calibrated Thematic Mapper Class Data for Carbon Cycle Studies, P. I., Brian Markham, Co. P.I. John Barker, Funded under Carbon Cycle NRA(NRA-00-OES-08), 3 years.

Interdisciplinary Analysis of Childhood Asthma in Baltimore MD. E. Levine and D. Kimes. (\$250K) Unsolicited Proposal, NASA Environment and Health program (Dr. Nancy Maynard)

Strengthening the Role of Soils in the GLOBE Student-Teacher-Scientist Partnership. E. Levine and S. Stockman (\$210K), Renewal of GLOBE project grant (NSF)

NASA/UMD Analysis of Medicaid Data to Help Assess the Relationships between Environmental Conditions and Childhood Asthma. C. Blaisdell and E. Levine. (\$270K) Health Care Finance Agency (HCFA)

Learning Materials to Support the GLOBE Soil Science Investigation. E. Levine (\$10K), Soil Science Society of America

Determining Photosynthetic Efficiency and Carbon/Nitrogen Cycling in Vegetation using Active and Passive Fluorescence Techniques, PI, E.M. Middleton, NASA Terrestrial Ecology Program, Carbon Cycle Science NRA, FY'02-'04.

EOS Validation Project (SAVE) selected for 6-month extension, PI J. Privette.

Awards

John Barker: NASA Exceptional Achievement Medal

Tom Brakke: GSFC Special Act Award.

Emmett Chappelle: NASA Exceptional Service Medal

Brent Holben: NASA Exceptional Achievement Medal

Jim Irons: GSFC Special Act Award

Arlene Kerber: GSFC Special Act Award

Arlene Kerber, GSFC Time Off Award

Bob Knox: Co-author of paper winning "Best Letter Award" for the best letter published in the International Journal of Remote Sensing during the year 2000. "Volumetric lidar return patterns from an old-growth tropical rainforest canopy". Int. J. of Remote Sensing, 21, No. 2, 409-415. Presented by the Remote Sensing Society and Taylor & Francis.

Elissa Levine: GSFC Special Act Award

Jeff Masek: Co-editor, Landsat-7 Special Issue of Remote Sensing of the Environment.

Betsy Middleton: GSFC Special Act Award

Jeff Privette: GSFC Special Act Award

Jeff Privette: Advisor, National Research Council's Associate Programs.

James Smith: Editor, "Institute of Electric & Electronics Engineers (IEEE) Transactions on Geoscience and Remote Sensing".

James Smith: Member, IEEE Fellows Committee

Biospheric Sciences Branch External Review Committee

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